Computers, Environment and Urban Systems 114 (2024) 102194

Contents lists available at ScienceDirect

Computers, Environment and Urban Systems

journal homepage: www.elsevier.com/locate/ceus

Experiencing the future: Evaluating a new framework for the participatory co-design of healthy public spaces using immersive virtual reality

Gamze Dane [a,*], Suzan Evers [a], Pauline van den Berg [c], Alexander Klippel [b], Timon Verduijn [b,d], Jan Oliver Wallgrün [e], Theo Arentze [a]

[a] *Department of the Built Environment, Eindhoven University of Technology, PO Box 513, 5600MB Eindhoven, the Netherlands*
[b] *Cultural Geography Research Group (GEO) & WANDER, Wageningen University & Research, P.O. Box 47, 6700 AA Wageningen, the Netherlands*
[c] *Fontys University of Applied Sciences, Rachelsmolen 1, 5612 MA Eindhoven, the Netherlands*
[d] *WANDER, Wageningen University & Research, P.O. Box 47, 6700 AA Wageningen, the Netherlands*
[e] *Independent Researcher, Helgolandring 10, 22926 Ahrensburg, Germany*

A R T I C L E I N F O

Keywords:
Immersive virtual reality
Public participation
Participatory design
Co-design
Urban public space
Citizen engagement
Healthy public space

A B S T R A C T

Urban densification is promoted for sustainable urban growth, yet it also generates concerns about negative health impacts on local citizens. Engaging local citizens in the co-design of densification projects is therefore crucial to address their needs and concerns. The use of immersive Virtual Reality (VR) technologies creates potential for advancing the participatory co-design of healthier urban spaces by allowing citizens to not only visualize but also experience the impacts of future designs or "what-if" scenarios. Theoretically grounded in an extended version of Sheppard's approach, which we call the Experiencing the Future Framework (EFF), we developed a study to create and evaluate an immersive VR application called CoHeSIVE. This application was designed to facilitate participatory co-design processes for healthy public spaces. CoHeSIVE, as the technological manifestation of our framework, was created through iterative workshops with end-user input. During the final workshop with 41 participants, both qualitative and quantitative data were collected, including user behavior and experiences with CoHeSIVE, especially regarding its experiential and interactive components. The vast majority of participants had positive experiences and recommended CoHeSIVE for participatory co-design processes. Participants felt confident in their design outcomes and found the user interface easy to use and effective for making and communicating design decisions. The most preferred design attributes were found to be many and clustered trees, several benches, large grass areas, high-rise buildings, more lampposts and the presence of a fountain, showing that the design outcomes were meaningful for the selected local context. Future enhancements of CoHeSIVE might include adding more design attributes, enhancing visual representations, adding multi-user capabilities, integrating generative AI and expanding CoHeSIVE's applicability to other contexts.

1. Introduction

Public participation in urban planning and design targets the involvement of citizens, designers, and other stakeholders in urban projects throughout the design process. This ensures that the design and decision-making task is not solely the responsibility of an individual expert, but rather the result of the collective creativity of a team of stakeholders with varying backgrounds and interests (Steen, 2013). Meaningful, active, and collaborative engagement of stakeholders (including citizens) in urban design has long been a crucial topic in the research and practitioner community (Arnstein, 1969; Thorpe, 2017; Daher et al., 2021; Turken and Eyuboglu, 2021). Involving the public in urban design can enhance collaboration and foster citizen ownership of the project (Kunze et al., 2011; Urton & Murray, 2021), potentially resulting in designs that are more representative of the needs and preferences of citizens and communities (Amado et al., 2010). Participatory urban design is expected to result in higher levels of user satisfaction and better utilization of urban environments for citizens' well-being (Toukola & Ahola, 2022; Wilson et al., 2019). Typically, for participatory urban design, co-design workshops are held to facilitate the active engagement of citizens and other stakeholders. Through a collaborative approach, co-design workshops enable participants to

* Corresponding author.
E-mail address: g.z.dane@tue.nl (G. Dane).

https://doi.org/10.1016/j.compenvurbsys.2024.102194
Received 17 May 2024; Received in revised form 7 August 2024; Accepted 11 September 2024
Available online 21 September 2024

have a shared understanding of the challenges and potentials of the project area (Liu et al., 2019; Williams et al., 2019) and to develop solutions while incorporating diverse perspectives and promoting inclusivity (Healey, 1998; Sanders & Stappers, 2008; Smith & Iversen, 2018; Webb et al., 2018). In that sense, it is necessary for citizens and urban planning stakeholders to have efficient discussions, comprehend and communicate the consequences of alternative urban design scenarios. This process serves two key purposes: (i) enhancing an inclusive planning practice by fostering participation and communication among stakeholders and citizens, and (ii) facilitating informed decision-making in urban design and planning.

Our cities are facing major problems such as housing shortages and the need for sustainable growth due to the increasing world population and diminishing resources. To tackle such issues, the densification of inner cities has been one of the potential solutions proposed to reduce land consumption and promote eco-friendly modes of transportation (Honey-Rosés & Zapata, 2021; Lu et al., 2018). However, it is also argued that high-density urban areas can have negative health impacts on citizens (Cramer et al., 2004). Despite the potential advantages, densification projects raise concerns for local citizens, especially regarding the negative environmental stressors that can occur in urban public spaces, such as increased traffic and crowds, increased noise and nuisance, changing neighborhood character and reduced feelings of safety and comfort, which are associated with higher risks of mental and physical health problems (Honey-Rosés & Zapata, 2021; van Veghel et al., 2024; Mouratidis, 2019). It is crucial to engage local citizens and communities in the co-design of densification projects, especially to address their needs and concerns and to create urban public spaces that can enhance the well-being of citizens.

Urban public spaces, such as urban plazas, can, directly and indirectly, enhance the well-being of citizens, by supporting them in becoming more physically and socially active and by creating outdoor environments conducive to the reduction of stress (Khateeb & Shawket, 2022). One of the negative issues attributed to densification is the loss of nature in the cities. However, nature elements such as green spaces and water in urban plazas can have restorative effects, reduce stress, and encourage physical activity and social interaction (Sugiyama et al., 2018; Wood et al., 2017). Another potential issue with high-density urban areas is the lack of social ties, especially with neighbors (Mouratidis, 2019). Therefore, the provision of sitting and meeting places in urban plazas such as benches can contribute to positive perceptions of comfort and conviviality and increase social interaction (Legge, 2020; Mehta, 2013). Additionally, the presence of elements such as streetlights and waste bins is indicative of a well-maintained urban public square and can increase the feeling of safety and cleanliness (Mehta, 2013; Wirdelöv, 2020), which are some of the reported issues in high-density urban areas (Mouratidis, 2019). Although design elements of an urban public space that can enhance the well-being of citizens are universal, since urban public spaces can vary by their use and their users, it is necessary to consider a place-specific (local) approach and the variety of local (potential) citizens and citizens' needs while designing such areas (Alwah et al., 2021; Mehta, 2013). However, current co-design and participation practices for urban design and planning usually rely largely on participation sessions facilitated through traditional methods such as paper maps and 2D sketches (Evans-Cowley & Hollander, 2010; Wilson et al., 2019), which can be difficult for laypeople to comprehend and to envision the potential consequences of the proposed urban interventions (Van Leeuwen et al., 2018; Mueller et al., 2018).

Engaging citizens actively in the design process of urban public spaces and thinking along the potential future urban interventions via co-design workshops ensures that these public spaces reflect the diverse needs and preferences of citizens. This approach can increase inclusivity in cities and therefore can also contribute to the well-being of their citizens (Mannarini et al., 2010). The recent surge in the digitalization of urban design and planning practices is also attributed to its potential for facilitating participatory processes and citizen engagement (Shin et al., 2024; Wilson et al., 2019). It has been demonstrated that participatory co-design workshops can utilize various tools and visualization techniques such as 2D drawings, interactive maps, 3D models, augmented reality (AR), and virtual reality (VR) to support active engagement and facilitate communication between citizens and stakeholders in urban design processes (Borgers et al., 2010; Van Leeuwen et al., 2018); Wolf et al., 2020; Ehab & Heath, 2023). While the value of digital visualizations for designing and planning for the future has long been recognized (e.g., Sheppard, 2005), the role that immersive technologies such as Virtual Reality (VR) play in this process has only been explored recently (e.g., Van Leeuwen et al., 2018; Matthys et al., 2023). As a result, a range of novel tools aimed at enhancing participation, using eXtended Realities (XR), have emerged (Matthys et al., 2023; Evers et al., 2023, Van Leeuwen et al., 2018; Schrom-Feiertag et al., 2020). These tools aim to inform participants about future spatial plans while enabling them to experience these plans (Schnabel and Chowdhury, 2020; Chowdhury and Schnabel, 2019). In principle, immersive technologies can support users in experiencing the potential urban design scenarios, increasing the comprehensiveness of spatial environments, allowing them to immerse themselves in the design while reducing the potential distractions. Additionally, through embedded tracking technologies, immersive technologies can provide insights into the decision-making process of individuals and groups (Casini, 2022; Lyu et al., 2023; Wolf et al., 2020). Although the potential of visual communication can vary from information sharing to simulating different "what-if" scenarios for supporting participants' collective decision-making (Shin et al., 2024), most of these newly emerged tools rarely go beyond one-way information provision rather than leveraging the interactive opportunities that these tools offer.

Looking into earlier digital tools such as web-GIS, which were created to support participatory processes, reveals common problems. These include concerns about the reliability of user-generated content due to users' lack of domain knowledge, social exclusion due to the unease of using the developed technology, and the interpretation of digital outputs for meaningful discussions due to unfamiliarity with technical measures and/or the inability to connect the outputs with a local case (Van Cauwenbergh et al., 2018; Pfeffer et al., 2013). Newly emerging VR-based participatory-enhancing tools are not that different in that sense as they usually require extensive training and specialized hardware for the VR applications; use software that is difficult for laypeople to comprehend; and the application may be too generic and not associated with a local planning/design process, limiting their accessibility, localization, and democratization (Davies, 2004; Zarraonandia, et al., 2016). According to Van Cauwenbergh et al. (2018), involving stakeholders in the design of digital participation tools through iterative workshops can increase the accountability of the models, functionalities, and outcomes of the tool and also make the tool accessible, transparent, and localized. However, current VR-based participation tools are often developed without the input of (potential) end-users. Developing such smart city solutions without the input of (potential) end-users can carry risks such as the exclusivity of developed apps and the marginalization of population groups who cannot access the information and applications (Jiang et al., 2023). Therefore, representing the local community is necessary not only in the use phase but also in the design and development phase of these tools (Namatama, 2020). Moreover, current studies employing VR as a participation tool usually report qualitative findings such as only surveys or protocol analysis (i.e.; Chowdhury and Schnabel, 2019; Ehab & Heath, 2023) without examining measurable results. This is, however, an essential step to ascertain whether the tool can adequately and easily support participants in making their design decisions and aligns with users' qualitative judgments (Van Cauwenbergh et al., 2018).

In this paper, we briefly review and discuss the opportunities that immersive technologies, particularly immersive Virtual Reality (IVR), create for advancing participatory co-design of urban spaces (Section 1.1). After reviewing the literature, we selected Sheppard's framework of participatory co-design due to its capacity to address the above-mentioned gaps in the literature for developing participatory-enhancing tools, namely a local, visual and connected approach. By integrating the affordances of immersive VR into his approach, we conceptually extended the existing framework and coined the name "Experiencing the Future Framework" for our theoretical expansion (Section 1.2). To provide a thorough empirical evaluation of the new framework, we engaged in a comprehensive, iterative design process and developed an immersive VR application called CoHeSIVE (**Co**-designing **He**althy Public **S**paces through **I**mmersive **V**irtual **E**nvironments). As the manifestation of the new framework, CoHeSIVE app has been evaluated both qualitatively and quantitatively in participatory co-design workshops (Section 2). Results, discussion, and outlook (Sections 3–5) demonstrate the potential of integrating experience-affording digital tools, such as IVR, for enhancing participatory co-design processes.

1.1. (Immersive) Virtual reality and participatory co-design practices

Advancements in technology and computing power have facilitated the use and usability of immersive technologies, also now referred to as eXtended Reality (XR). These technologies include augmented, virtual, and mixed reality. Virtual Reality (VR) is characterized as "an alternate world filled with computer-generated images" (Steuer, Biocca, & Levy, 1995), affording the experience of "being somewhere else (virtual world)" (Rzeszewski & Orylski, 2021). A common ground in the literature for the definition of (immersive) VR is that it should have features of technological immersion and interactivity in a virtually presented world (Sherman & Craig, 2003). As VR technology has matured, its applications in participatory co-design practices for urban design and planning have emerged, offering new opportunities in these fields.

The complex challenges confronting our cities necessitate an integrated and cooperative planning approach. This approach should involve a diverse range of decision-makers, stakeholders from various sectors, and the general public in urban design and planning processes (Oomen et al., 2024). Despite the growing recognition of the importance of such an inclusive approach, public involvement remains low, particularly in the initial phases of design and planning (Cleaver, 1999). Although the opportunity to influence designs and plans is greater in the initial phases, the low level of participation is often due to the high level of abstraction of designs presented with 2D or 3D images or models and associated texts (Wolf et al., 2020). VR technology offers the possibility to create virtual environments that do not yet exist in the real world, to visualize future urban developments (Portman et al., 2015). Through its immersive capabilities, VR can create the conditions necessary to induce a sense of spatial presence (Rzeszewski & Orylski, 2021). This makes it easier for participants to perceive the scale of the new urban design and development plans and to create a more visceral connection to future urban designs (Paes et al., 2017) while reducing task-unrelated thoughts and factors (Van Leeuwen et al., 2018). This immersion can engage users and help them understand and feel changes in urban spaces which is crucial in participatory planning. The interactivity feature of VR technology enables users to shape urban environments through design freedom of (re)creating any design scenario and experiencing the consequences of a scenario in the virtual environment in a risk-free and cost-efficient way (Wolf et al., 2020). This also offers the possibility of making and comparing different design scenarios. This feature is particularly important for co-designing multiple "what-if-scenarios" that can be experienced in a shared way and discussed by all participants to build consensus during the early phases of the design and planning process.

The common ground for all these technical developments is that they allow for accessing future states of the urban environment that consist of both social and technical components in a more realistic, visual, and visceral (human) way (Rzeszewski & Orylski, 2021; Wolf et al., 2020)). The emergence of mass-media immersive technologies (Scoble & Israel, 2017) and efficiently creating virtual worlds for future states of our environments (Huang et al., 2021) provide now the opportunity to make urban models and what-if scenarios experientially accessible at scale and integrate them into participatory, co-design sessions for active and meaningful participant engagement. Moreover, the tracking capabilities of VR technology allow for understanding and validating how users interact with the virtual (built) environment (Caserman et al., 2019). Finally, VR technology typically provides reproducible and standardized solutions that can be replicated for different contexts and areas (Wolf et al., 2020).

1.2. Experiencing the future framework

In contrast to the technological advancements, the role of immersive technologies has not received enough conceptual attention, and its connection to existing theories still requires further development, especially for participatory co-design approaches. We therefore turn to the ground-breaking efforts of visualizing climate change and planning for the future by Sheppard (2005, 2012, 2015). He detailed the opportunities that visualizations, especially 3D visualizations, offer and distilled three guiding principles for realizing successful participatory approaches: *make it local, make it visual, and make it connected.* Based on our brief review above, immersive technologies such as VR allow for adding two additional dimensions. The first dimension is to include embodied experiences in the process, *make it experiential.* This dimension is not orthogonal to the three already named; however, it is essential to explicitly add it, given the paradigmatically different characteristics of immersive technologies. Through immersive technologies, participants become part of the very representation that is used for communication and decision-making by experiencing data rather than merely observing it (Lee et al., 2021; Klippel et al., 2020; Simpson et al., 2017). The second dimension is to *make it interactive.* Interactivity provides opportunities for enhanced and active engagement, changing perspectives, and retrieving additional information. Interactivity, combined with immersive technologies, also offers the possibility to explore and experience so-called *what-if scenarios* (see section 1.1), which can provide embodied, experiential access to the consequences that our decision-making has on the environment, economic aspects, but also our personal and emotional responses to environmental change (Potkonjak et al., 2016; Pellas et al., 2021). This latter topic has a long history in modeling, simulation, and serious game communities, and more recently in the evolving area of city digital twins (Jones et al., 2020; Batty, 2024).

The value of experiencing the future states (what-if scenarios) has long been recognized (Jamei et al., 2017), but only through immersive technologies and advances in modeling these experiences are becoming part of co-design efforts at scale. Considering co-design tools in urban design and planning practices, which involve non-experts and non-designers in the urban design process, interactivity needs to be easy, accessible, and intuitive (Baldauf et al., 2023; Van Leeuwen et al., 2018; Jerald et al., 2017). This ensures that non-experts can interact with the provided 3D models and engage in the design task without facing technical barriers and extensive training, while still having flexibility in design options so that their design outputs are meaningful and the results are interpretable. This also necessitates developing these tools in a transparent way, especially regarding the experiential and interactivity components, based on the requirements and needs of end-users (Pettit et al., 2014; Pettit et al., 2018). In line with experiences from previous digital tools to support participatory processes (Van Cauwenbergh et al., 2018; Pfeffer et al., 2013), IVR-based tools should be designed and developed through an iterative process involving end-users and stakeholders with a local, relatable, and current challenge as a case study.

To summarize, building on Sheppard's work, we propose the following *Experiencing the Future Framework* for creating and theorizing IVR-based participatory co-design tools in urban design practices:

- **Make it local** (a place-specific approach by using the local landscape and its challenges),
- **Make it visual** (utilizing the power of visual perception),
- **Make it connected** (linking the local landscape, user needs and perception, and the societal challenges, in our case designing a healthy public space in a densification area),
- **Make it experiential** (as an embodied experience using immersive technologies),
- **Make it interactive** (to experience what-if scenarios easily and intuitively).

In the following methodology section, we describe the development of the CoHeSIVE app as our proof-of-concept implementation of this approach. The third section presents the data and results of this study, followed by a section where we discuss the findings while referring back to the framework we proposed. The final section presents the conclusions and outlook for our approach.

2. Methodology

Following our *Experiencing the Future Framework* to advance our understanding of the opportunities and challenges of VR for participatory co-design efforts, this study developed and tested an immersive virtual reality (IVR) application prototype (namely CoHeSIVE) for co-designing a healthy public space in a regeneration area in Eindhoven. Through a series of iterative workshops with the involvement of a variety of stakeholders, we developed and evaluated CoHeSIVE app so that user requirements and needs could be considered in the development. Fig. 1 illustrates the iterative design process and its relation to *Experiencing the Future Framework*.

The first three principles of *Experiencing the Future Framework* were realized by selecting a case area and embedding it into the local landscape, using 3D visualizations. Designing the area was connected to societal and environmental challenges. The design attributes were meticulously tailored to the specific location, ensuring that the design process aligns seamlessly with the unique characteristics of the selected case area and the needs of the current and potential users of the area. The baseline design was adapted from the actual plans of the area created by the companies and the municipality involved that are responsible for the regeneration project. This emphasis on locality enhances the relevance and authenticity of the design outcomes, aiming to create a more meaningful and impactful connection with its users and a contribution to the overall design discourse. All three aspects (the local landscape, user needs and perception, and the societal challenges) were connected to each other in an initial prototype application which was used to test and collect user feedback.

To realize the fourth principle, *make it experiential*, immersive technologies were used to create embodied experiences. Grounding communication and co-design in shared stakeholder experiences aimed at encouraging enhanced engagements of citizens and designers in an urban design task. An essential factor in choosing to develop an IVR application was based on its capability of delivering an interactive, embodied, and visceral experience of current and future states of reality (Barbot & Kaufman, 2020; Bouzguenda et al., 2022; Chassin et al., 2022). At this stage, the level of realism was also decided based on user needs and feedback. For the fifth principle, *make it interactive*, CoHeSIVE takes a unique approach. In contrast to existing interactive IVR applications such as Arkio and Revit and applications specifically developed for some studies such as Chowdhury and Schnabel (2019) where users have unrestricted design freedom including the creation of shapes in any

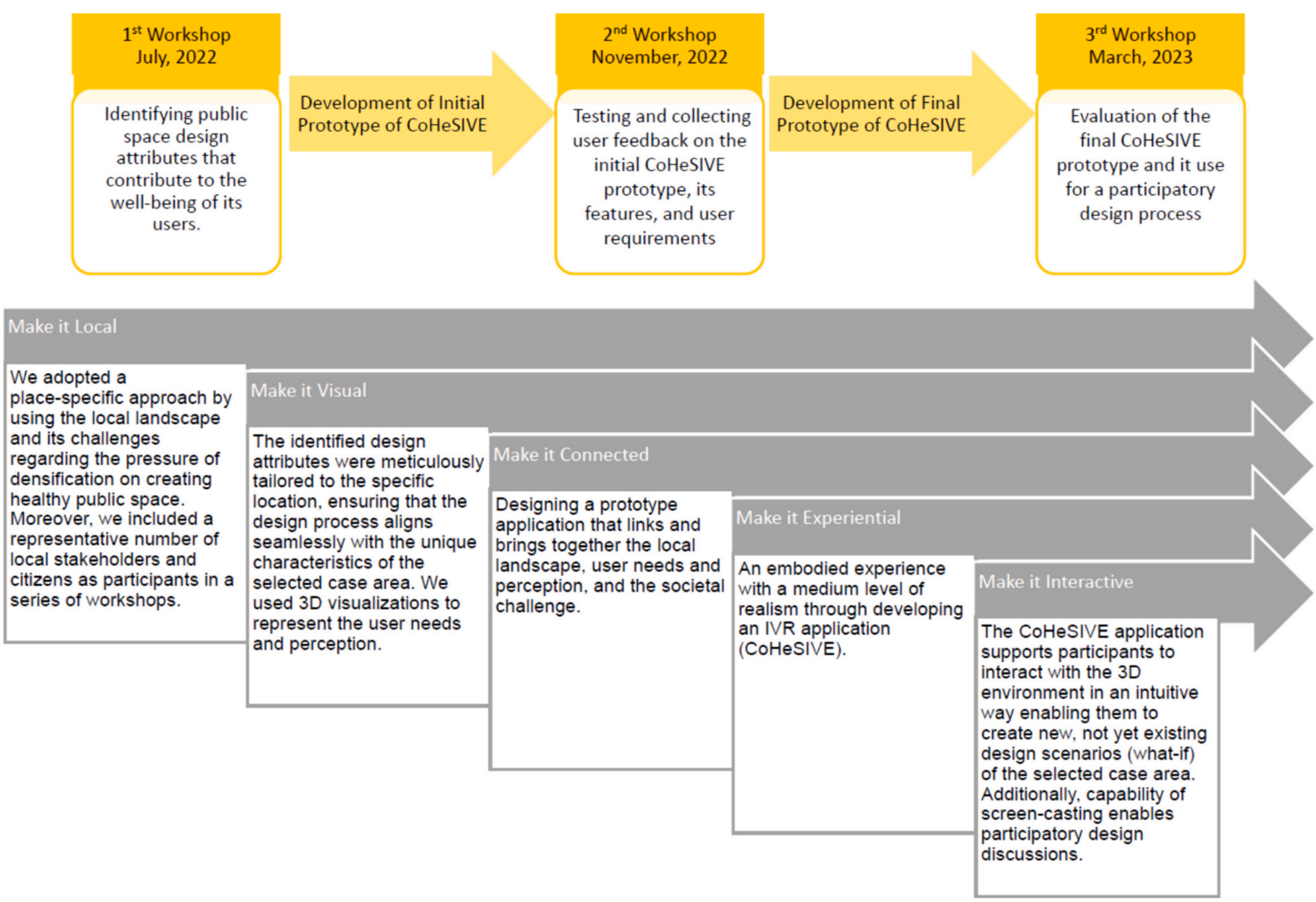


Fig. 1. Iterative Design Process and its relation to Experiencing the Future Framework.

size and quantity, CoHeSIVE introduces an innovative methodology to incorporate intuitive design decisions based on modifications within a simulated environment (as described earlier in our short-paper publication (Evers et al., 2023). Within CoHeSIVE, users can decide on the pre-defined and varying quantities, positioning, and sizes of given attributes, thereby actively participating in the design generation process. The application automatically generates new design scenarios when a user selects a level of a predefined design attribute. The primary motivations behind this development philosophy were to make the public space design process accessible to non-experts and also to eliminate the need for extensive training associated with new technology. This approach recognizes that non-experts, lacking a design background and/or familiarity with VR technology, may struggle with immediate design generation. The CoHeSIVE application aims to support participants to interact with the 3D environment in an intuitive way for enabling them to create new, not yet existing design scenarios of the selected case area. In that way, the application is aimed to be a more democratic, accessible and localized co-design tool. In addition to the inherent interactivity of the tool, it is also possible to screen-cast a user's design process through a laptop and a large screen. By exploiting this functionality of the VR devices, we added more interactivity to the process which enhanced the participatory process by means of a group discussion of a user's design decisions projected on a large screen.

This section further provides an overview of the designated case area. Subsequently, the two workshops utilized in the development and testing of the CoHeSIVE application are explained. This is followed by a discussion of the technical aspects of the application and its comprehensive evaluation at the third workshop.

2.1. Overview of the case study area

This research considers the re-design of the central station plaza in the city of Eindhoven. Eindhoven is the 5th largest city in the Netherlands with approximately 225,000 residents and is situated in the southern part of the country. The city's population is on the rise, driven by appealing job and educational opportunities, leading to a housing shortage. To deal with the housing shortage sustainably, the city of Eindhoven aims to increase population density in the inner city. The large-scale redevelopment of the station area in the inner center of Eindhoven is set to transform this location, currently accommodating 200 inhabitants, into a mixed-use environment for approximately 15,000 inhabitants (Municipality of Eindhoven, 2021). Consequently, the user demographics of the existing station plaza will undergo a significant shift.

The plaza primarily caters to train passengers arriving on foot, by bike, or through the park & ride facility. However, in the future, this public space will also play a crucial role for residents in the planned, surrounding high-rise buildings. This transformation poses new challenges in developing healthy and dense inner cities, particularly concerning the public realm. Densification is usually associated with negative consequences in public spaces, such as increased traffic, crowds, noise and nuisance and reduced feelings of safety, physical and restorative activities, and social interactions, which can result in mental and physical health issues for residents (Honey-Rosés & Zapata, 2021; Mouratidis, 2019). These types of concerns have already been brought to the agenda of the city of Eindhoven by several citizen associations such as EHVXL. To accommodate the needs of the influx of new residents and visitors resulting from the construction of new dwellings and offices, it is essential to enhance this station plaza with qualities that align with the needs of both current and future users, supporting functionality and their overall well-being. Fig. 2a illustrates the current state of the station plaza, while Fig. 2b depicts the proposed redevelopment plan for the station area.

2.2. Iterative design of CoHeSIVE

Through a series of three workshops, each with different yet complementing aims, the potential end-users (citizens and stakeholders) actively contributed to the iterative and comprehensive design and evaluation of CoHeSIVE. This comprehensive iterative design approach (as seen in Fig. 1), allowed for sharing of their wishes and preferences for such an application but also delivered empirical data from the use of CoHeSIVE. We actively recruited diverse participants and stakeholders for the workshops, including graduate students, academics, VR developers, representatives from the municipality of Eindhoven, and project developers in the case study area.

The first workshop, held in July 2022, focused on identifying public space design attributes that contribute to the well-being of its users. In the first part of the workshop, participants were presented with images illustrating a variety of public space designs, especially station plazas. Participants then explored these images and identified 25 user well-being-related attributes (shown in Appendix A, Table 1), consistent with the academic literature (i.e.; Kim et al., 2020; Liao et al., 2022; Mehta, 2013; Van den Berg et al., 2022; Van Vliet et al., 2021). In the second part of the first workshop, participants rated the most important attributes for a public square on a five-point scale for their importance and also suitability in an IVR application (shown in Appendix A Table A2 and Fig. A1). The output of this first workshop informed the selection of the attributes for the CoHeSIVE application. These findings, combined with existing literature and possibilities in developing an IVR application, led to the selection of seven design attributes for the CoHeSIVE prototype. These attributes include the presence of trees and tree composition, the presence of benches, building height, the presence of lighting posts, the amount of grass (defining the width of walking paths), and the presence of fountains.

The second workshop, which was described in our short-paper

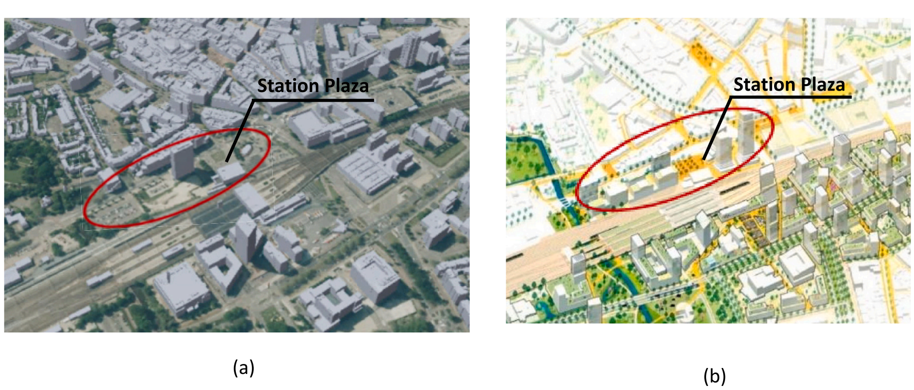


Fig. 2. (a) Current situation of the station plaza and its surroundings (Source: © 3DBAG by tudelft3d and 3DGI, 2024) (b) Future redevelopment plan of the station area (KnoopXL) Eindhoven (Source: Municipality of Eindhoven (2021)).

Table 1
Attributes, Attribute Levels, the relation of attributes to health, and the Default Base Levels as shown in CoHeSIVE.

Sequence of Attributes shown in the app	Attribute	Attribute level					Relation to health (defined in the first workshop)	Default Base Level
		Level 1	*Level 2*	*Level 3*	*Level 4*	Level 5		
1	**Presence of trees**	None	Few	Several	Many	No Preference	In relation to **restorative, walkable, social** spaces	None
2	**Tree composition**	Spread	Clustered	No Preference	–	–		Spread
3	**Presence of benches**	None	Few	Several	Many	No Preference	In relation to **restorative, social** gathering space	None
4	**Presence of grass coverage**	None	Small	Average	Large	No Preference	In relation to **walkable** spaces – determining walking space or width of pavement, as well as **restorative**	None
5	**Height of (new) buildings**	Skyscrapers	High-rise	Medium-rise	Low-rise	No Preference	In relation to air movement, heat and human scale	Skyscrapers
6	**Presence of lamp posts**	Less	More	No Preference	-	-	In relation to **restorative, walkable, social** spaces *(degree of safety)*	Less
7	**Presence of water fountain**	No	Yes	No Preference	-	-	In relation to **restorative, social** gathering space	No

publication (Evers et al., 2023), was held in November 2022 to test and collect user feedback on the CoHeSIVE prototype, its features, and user requirements. Nineteen participants attended the workshop, during which they received a clear and standardized explanation of how to use the application, followed by a design task for the participants. Participants were briefed that their attribute selection is about a healthy public space design, meaning that their design choices should be able to enhance their well-being and create a station plaza where they would feel relaxed/comfortable to spend time. After this, participants were divided into four groups to alternately try out the developed CoHeSIVE prototype using Meta Quest 2 VR headsets. In the second part of the second workshop, participants completed a questionnaire to self-report their experiences and give feedback. The received feedback and comments at the second workshop, detailed in Evers et al. (2023), were taken into account to further improve CoHeSIVE.

2.3. *CoHeSIVE - the final application and final evaluation*

Implementing a comprehensive tool for realizing our Experiencing the Future Framework and following our iterative design approach, the feedback from the previous workshops was used to further design and improve the utility of CoHeSIVE. Below, we provide a short overview of the main design choices for CoHeSIVE and then detail the data collection and evaluation in the third workshop.

2.3.1. *CoHeSIVE final application*

One essential design characteristic of CoHeSIVE is that it allows users to adapt a given base-level scenario according to their preferences by altering the levels of design attributes. This approach frees users from a focus on design-skills to interactively and experientially explore the effects of urban design choices. This development, as confirmed by users of the second workshop, allows for the effective, intuitive, and user-friendly realization of the experiencing the future framework. In the application, a selection panel per attribute is shown sequentially (as can be seen in Fig. 3b and c) with pop-up buttons, and the user can move between attributes via the next or previous arrow-button. After clicking the pop-up button for an attribute, the user sees the levels of the given attribute. The user can alter the given seven attributes by selecting preferred attribute levels (options, see Table 1). Given the number of attributes and their levels, a total of 2048 possible design scenarios are available to the user. The availability of large numbers of possible design scenarios is meant to give users design flexibility.

CoHeSIVE automatically generates a new design scenario each time the user selects an alternative level for a particular attribute. The user may not be satisfied with the result, and again change levels of particular attributes, where the system automatically regenerates a new design until the user is satisfied with their design. Attributes, their levels, their relation to health, and the default base levels shown in the CoHeSIVE application can be seen in Table 1. In addition to the prefixed attribute levels, the user can also opt for a no-preference level (N/P). Furthermore, the application tracks the user's interaction with the virtual environment by tracking their selected attribute levels, measuring the duration between each selection, quantifying the number of clicks made before deciding on an attribute level, recording the number of viewpoints utilized, and collecting data on the head movements performed during the design process.

We kept the fidelity of the models used in CoHeSIVE at a low to medium level. This choice was actively made based on the received user feedback and the advantage of scalability outweighing the expensive opportunity to create high-fidelity models. CoHeSIVE is developed as a stand-alone, resource-efficient application that was scripted in the game engine software Unity3D and runs on off-the-shelf headsets such as the

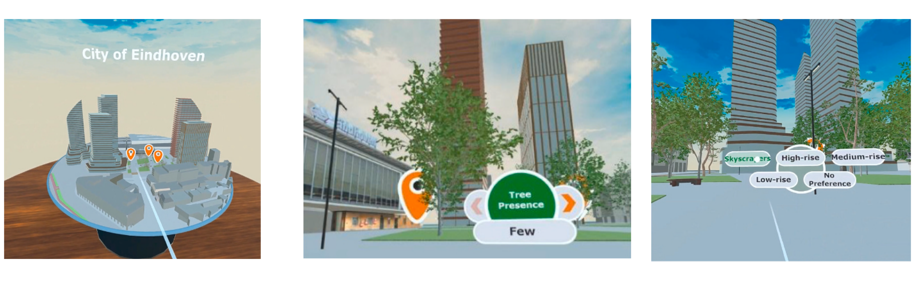


Fig. 3. Impression of the refined CoHeSIVE IVR application and its features (a) Bird-eye view with three orange teleport flags, (b) selection panel for attribute "Tree Presence", (c) selection panel with options for attribute " Building Height".

Meta Quest 2. A video of the application can be found in Supplementary Materials 1. The opportunity for collaboration was realized through screencasting to combine immersive experiences with realistic social settings (but see the Outlook section for a discussion on collaboration alternatives).

Important additions included the provision of experiencing different scales (Zhao & Klippel, 2019). At the start of the CoHeSIVE experience, the user is shown a bird-eye perspective of the simulated location, to familiarize themselves with the context of the station square. Within the application, the user can switch between a bird-eye and three egocentric eye-level viewpoints by using the controllers in combination with the controller buttons of the VR headset. Examples of a bird-eye and an egocentric perspective are shown in Fig. 3a and b.

2.3.2. CoHeSIVE - final evaluation

For the final evaluation of CoHeSIVE, the third workshop was held in March, 2023, featuring a participatory design session using the refined CoHeSIVE application and allowing us to gain insights into the user experience of both the application and the participatory design process. A total of 41 people participated in this workshop, in multiple sessions with approximately eight participants each. The workshop sessions started with an introduction to the project and an explanation of the design task. The context of a hypothetical situation was meticulously described, detailing (i) the future redevelopment of the area and the necessity to redesign the station plaza, and (ii) the framed circumstances (e.g., sunny weather, summer afternoon). The participants were asked to envision and design the station square in a manner that would make them most comfortable while waiting for a friend for 15 min. Similar to the second workshop, participants received a clear and standardized explanation of how to use the IVR equipment and the CoHeSIVE app. Fig. 4 shows examples of the explanation.

Participants could design the station plaza using CoHeSIVE within Meta Quest 2 headsets, with each design session limited to 10 min per participant. This timeframe aimed to prevent prolonged exposure to the simulated environment and potential negative side effects while also being appropriate for the given design task. Users were asked to go through all the seven attributes and encouraged to try different attribute options. Users were not given any lower or upper limit in terms of the number of attributes to be changed. After the design session, a plenary discussion was held also where one participant was asked to verbally convey his/her design decisions while being immersed, and the process was screen-casted to the other participants on a large screen (see Fig. 5). This allowed all participants to discuss the reasoning behind their similar or different decisions. This discussion gave an indication for the use of the CoHeSIVE application in the negotiating and brainstorming phase in a participatory process. Finally, a survey was distributed to each participant to collect data on their personal characteristics, perceptions on spatial arrangement (immersion and presence), the methodology of designing (feeling of control, decision-making process), the collaboration experiences (participation and communication), and reflections on their self-made designs. The survey is provided in Appendix B.

The collected data, through the CoHeSIVE application's tracking features, the survey, and the plenary session, allow understanding of the participant characteristics, participants' design decisions, participants' behavior in the CoHeSIVE application, and participants' feedback on the application and its use for participatory design. The collected data were examined and the results are presented in the next section.

3. Results

This section will provide the results of the third workshop including participant characteristics, their design decisions, their recorded behavior while designing with CoHeSIVE, and participants' feedback on CoHeSIVE, their designs, and an assessment of CoHeSIVE's value for participatory design.

3.1. Participant characteristics

As can be seen in Table 2, the majority of the participants were between 18 and 44 years old, satisfied with their lives, familiar with the station plaza of Eindhoven, living in a city center or city suburbs, and familiar with the use of IVR. 59 % of the participants had a design background. The majority of the participants didn't attend the first and second workshops. (See Table 2.)

3.2. Participants' Design decisions

CoHeSIVE recorded data from 41 participants shows that a total of 38 different designs were developed out of 2048 possible design scenarios. Only three designs were exactly the same, and the others were unique. Table 3 shows which attribute levels were predominantly selected (in percentages) and how the selected attribute levels diverged from the base level. As can be seen in Table 3, most of the participants

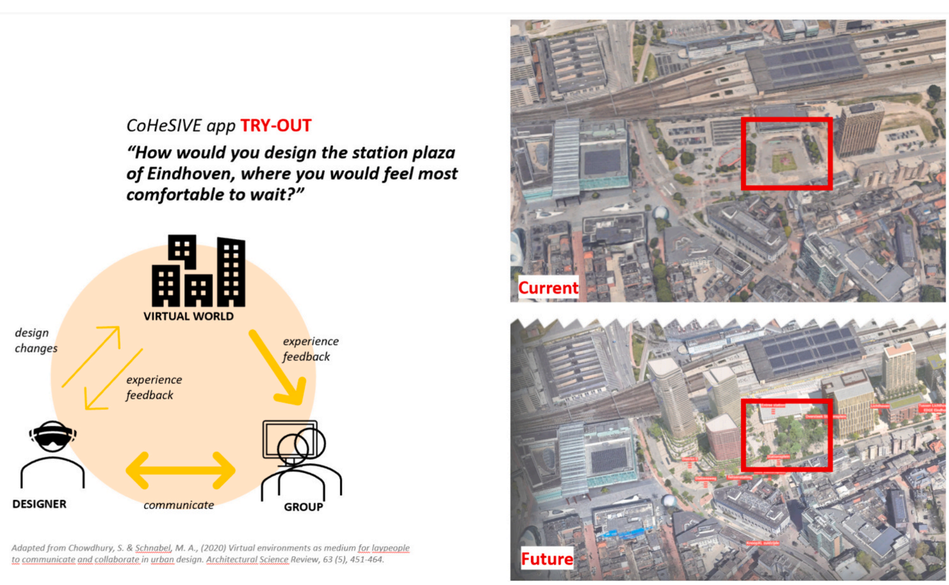
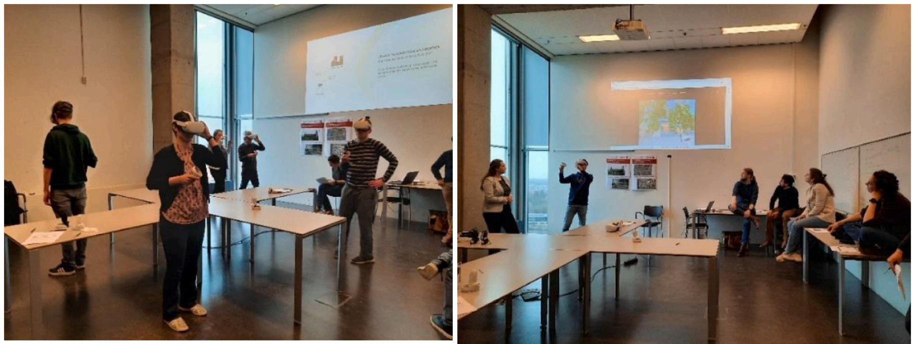


Fig. 4. Explanation of the design task and the use of the CoHeSIVE application.



(a) (b)

Fig. 5. Impressions of the third workshop (a) participants implementing the design task in the CoHeSIVE IVR app (b) Immersed participant showing and explaining his design decisions while other participants watching and commenting.

Table 2
Summary of demographics (*N* = 41).

Participant Characteristics		Number of participants	Frequency
Gender	Male	24	59 %
	Female	17	41 %
	18–25 years	7	17 %
Age	25–34 years	14	34 %
	35–44 years	9	22 %
	45–54 years	5	12 %
	55–64 years	5	12 %
	> 65 years	1	2 %
Familiarity with station plaza in Eindhoven (Visitation)	Daily	9	22 %
	Weekly	11	27 %
	1–2 per month	6	15 %
	Less than 1 per month	9	22 %
	Less than 1 per year	6	15 %

Table 2
(continue). Summary of demographics (N = 41).

Participant Characteristics		Number of participants	Frequency
Attendance previous workshop	Only Workshop 1	1	2 %
	Only Workshop 2	3	7 %
	Both Workshop 1 & 2	6	15 %
Design background	Yes	24	59 %
	No	17	41 %
	City Center	20	49 %
Urbanization level	City Suburbs	15	37 %
	(Small) Town	4	10 %
	Rural	2	5 %
	Very important	11	27 %
Importance of health in urban plazas	Important	13	32 %
	Neutral	12	29 %
	Unimportant	3	7 %
	Very unimportant	2	5 %
	Very familiar	10	24 %
Familiarity with use of IVR	Familiar	18	44 %
	Neutral	8	20 %
	Unfamiliar	1	2 %
	Very unfamiliar	4	10 %

preferred a green plaza, with many, clustered trees and a large grass surface. Striking is to see that for grass presence, none of the participants selected the option 'none'. In addition, the majority would like to have fountains in the plaza. Furthermore, most participants would like to have more lampposts and several benches. Although there was not a clear preference for building height, the high-rise was the most selected option followed by skyscrapers. Although the majority of the designs varied from each other, there seems to be a consensus on the most preferred attribute levels as can be seen in Table 3. By combining these most preferred attribute levels, we illustrate the desired design output in Fig. 6.

Looking at the survey data where participants were asked about their opinion on the importance for the given attributes on a 5-level Likert scale for their healthy station plaza design, it is seen that participants found on average “tree presence” as the most important attribute (see Table 4). “Tree presence” was followed by “bench presence”, “grass presence”, “tree composition”, “building height”, “lamppost presence”, and finally “fountain presence”.

In the survey, participants were also asked about their reasoning behind their created designs by means of their selected attribute levels and the expected impacts of their selections on the health and well-being of the users of the station plaza. Table 5 lists the reasons for choosing certain attribute levels, grouped under safety, restoration, social activity, physical activity, and hosting activities as indicators of health in terms of subjective well-being. These reasons were used in the follow-up participatory design conversation among participants, to discuss on the preferred attribute levels.

3.3. Participants' behavior while designing with CoHeSIVE

During the immersive, interactive design task, data was collected on the behavior of the participants through the application's tracking capabilities. Table 6 provides an overview of the behavioral data recorded during the design process. On average, it took participants four minutes to design the plaza and accomplish the design task with the use of CoHeSIVE (ranging from a minimum of one minute to a maximum of 12 min). Participants took on average 30 s to select a preferred attribute level per attribute, except the first attribute “tree presence”. Based on the average design time (60 s) of the attribute “tree presence”, it can be argued that it took around 30 s for participants to understand the user interface and familiarize themselves with the simulated world before they started with the design task.

During the immersive design process, participants clicked on average 50 times to go through attributes, to make the attribute level selections, and to switch between viewpoints. Only 29 % of the participants did not go back and forth between the attribute selection panels, but kept the attribute sequence fixed, while the rest of the participants re-considered their attribute level selections during the design process. Not all potential attribute level options were explored, especially for “tree presence”, “bench presence” and “grass presence”. Possibly, participants might have selected their initial preference, instead of trying out all options.

Participants used on average two out of three different viewpoints. Participants teleported between different viewpoints predominantly at

Table 3
Selected attribute levels in percentages.

Preferred attribute rank	Tree presence	Tree composition	Bench presence	Grass presence	Building height	Lamppost presence	Fountain presence
Default base level	*None*	*Spread*	*None*	*None*	*Skyscrapers*	*Less*	*None*
Most preferred level	Many (*51 %*)	Clustered (*54 %*)	Several (*59 %*)	Large (*56 %*)	High-rise (40 %)	More (66 %)	Yes (73 %)
Second most preferred level	Several (27 %)	Spread (32 %)	Many (27 %)	Average (27 %)	Skyscrapers (36 %)	Less (29 %)	None (20 %)
Third preferred level	None (14 %)	NA	Few (12 %)	Small (10 %)	Medium-rise (15 %)	NA	NA
Fourth preferred level	Few (8 %)	NA	None (2 %)	N/P (7 %)	Low-rise (7 %)	NA	NA
Least preferred level	N/P (0 %)	N/P* (14 %)	N/P (0 %)	None (0 %)	N/P (2 %)	N/P (5 %)	N/P (7 %)

* No preference for tree presence and therefore for tree composition.

Fig. 6. Snapshots from a scenario generated with the most preferred attribute levels: Many and clustered trees, several benches, large grass area, high-rise building, more lampposts and fountain presence.

Table 4
Importance of attributes on subjective well-being.

Importance of attribute	Tree presence	Tree composition	Bench presence	Grass presence	Building height	Lamppost presence	Fountain presence
Average importance (scale 1–5)	4,4	3,6	3,8	3,7	3,5	3,4	3,0
5 - Very important (%)	44 %	12 %	19 %	19 %	9 %	16 %	7 %
4 - Important (%)	49 %	49 %	49 %	46 %	46 %	37 %	25 %
3 - Neutral (%)	7 %	33 %	30 %	26 %	33 %	23 %	37 %
2 - Unimportant (%)	0 %	4 %	2 %	2 %	12 %	22 %	19 %
1 - Very unimportant (%)	0 %	2 %	0 %	7 %	0 %	2 %	12 %

the end of the process to experience their self-made design or at the beginning of the process to familiarize themselves with the surroundings. Only one-third of the participants used the teleport options throughout the design process.

We also collected head tracking data to understand participants' head movement and viewing behavior while experiencing the station plaza, such as horizontal, vertical, and rotational head movements (see Table 7). This information can provide further indications on which attributes of the IVR environment captured participants' attention. The resulting averages are summarized in Table 7 for each of the attributes. The five reported values are: (1) The distance moved around in the plane, not counting teleporting to a different location marker/viewpoint. While we are reporting this value in meters, these numbers are meant for relative comparison between the attributes and are not exactly scaled to the dimensions of the 3D model. (2) The sum of the rotational head movements in the vertical direction in degrees. (3) The angular range covered in the vertical direction; this is the angle interval between the highest and lowest view angle in degrees with a theoretical maximum of 180°. (4) The same as (2) but for horizontal head movements. (5) The same as (3) but horizontally with a theoretical maximum of 360° for horizontally looking in all directions. All these values were calculated after applying a filter to cancel out noise from very small camera movements, such as the normal camera shake when wearing a VR headset.

According to the results shown in Table 7, the "tree presence" attribute exhibited the highest values across all five categories. However, this could be because this attribute is the first one shown to participants when they teleport to a location inside the model for the first time. Therefore, the (head) movements recorded during this period include the time in which participants were familiarizing themselves with the new perspective. Considering the distribution of trees across the public space and the height of trees, this finding might also indicate that respondents took the time to look around while designing this attribute. This observation is also supported by the survey responses where "tree presence" was indicated as the most important attribute by the participants.

Additionally, "bench presence" and "building height" attributes also showed high values. The "building height" attribute had particularly high values in the vertical dimension (head/camera pitch), being the only attribute that involved significant changes in this dimension. Considering the varying height options for the proposed buildings in the public square, this finding confirms that participants looked vertically at how their building height selection influenced their design and experience. The "bench presence" attribute displayed high values for movement in the plane and the sum of horizontal head movements, indicating that participants tended to move around and look back and forth more while designing this attribute. This is expected as benches were positioned across the public space, and confirms that participants took the

Table 5
Participants' reasons for design choices on subjective well-being.

Attributes	Aspects of Subjective Well-being				
	Safety	Restoration	Social activity	Physical activity	Hosting activities
Tree Presence	Less trees for better overview and sight of space [9] More trees for more greenery levels [2]	**More** trees for shadow spots and less wind [20]		**Less** trees for better overview [3]	**More** trees for less obstacles [1]
Tree Composition	Spread trees for better overview and sightlines [2] Clustered trees for better overview and sightlines [2]		**Clustered** trees as example for people to cluster too [3]	**Spread** trees to walk around [4]	**Clustered** trees to make room for events (e.g., food trucks) [3]
Bench Presence	More benches to sit [3] Less benches for less obstacles [1]	**More** benches to sit [20]	**Less** benches to sit together [15] **Less** benches to urge strangers to sit together [1]	**Less** benches for less obstacles [1]	**More** benches to organize (work) meetings [5] **Less** benches for less obstacles [1]
Grass Presence		**More** grass to be less disturbed by commuters [9]	**More** grass as seating and playing opportunities [4]	**More** grass as play or sport field [5] **Less** grass for more walking space [1]	**More** grass to organize events (e.g., sports, picknicks [9] **Less** grass to organize events (e.g. festivals, protests) [3]
Building Height	Lower building height for less dark spaces [3] Higher building height for more social control [2]	**Lower** building height is less imposing [1] **Higher** building height creates unity in demarcation [1]	**Higher** building height to increase amount of people potentially using the plaza [1]		
Lamppost Presence	More lampposts for visibility (at night) [22]		**More** lampposts for visibility (at night) [1]		**More** lampposts for evening activities [1] **Less** lampposts for less obstacles [1]
Fountain Presence		**Presence of** fountain as entertainment [9]	**Presence of** fountain as meeting spot [5]	**Presence of** fountain as play area [6] **No** fountain for less obstacles [1]	**Presence of** fountain as play area [3]

Note: Numbers in brackets indicate the number of participants mentioning the subject.

Table 6
Collected data on user interaction with CoHeSIVE app.

	Tree presence	Tree composition	Bench presence	Grass presence	Building height	Lamppost presence	Fountain presence	Total session
Average design time (in seconds)	60	30	32,5	29	35,5	21	33	242
Average number of test clicks for selecting attribute levels	3	2–3	2–3	3	4–5	2	2	50
Average number of locations used	2	1–2	2	1–2	1–2	1–2	2–3	2

Table 7
Results from analyzing head tracking.

	Tree presence	Tree composition	Bench presence	Grass presence	Building height	Lamppost presence	Fountain presence
Average distance moved in the plane (in meters)	55.74 m	32.64 m	41.32 m	34.09 m	39.89 m	25.94 m	22.43 m
Average sum of vertical head rotations (pitch) (in degrees)	344.58°	135.34°	127.69°	100.83°	326.79°	91.76°	50.76°
Average vertical head rotation angle interval (pitch) (in degrees)	61.05°	33.34°	33.52°	26.36°	50.88°	28.66°	20.34°
Average sum of horizontal head rotations (yaw) (in degrees)	1214.17°	790.73°	961.42°	830.74°	921.98°	626.06°	468.93°
Average vertical head rotation angle interval (yaw) (in degrees)	279.22°	180.85°	209.84°	199.59°	253.98°	235.35°	195.83°

time to look around horizontally to observe all the benches. The survey also highlighted benches as one of the most important attributes. On the low end, we see particularly small values in all categories for "fountain presence" and also to a slightly lesser degree for "lamppost presence" (with the exception of vertical angle interval which has a relatively high value for "lamppost presence", as expected due to the height of a lamp post). Overall, the head tracking data supports the findings from the survey and user interaction tracking data.

3.4. *Participants' feedback on CoHeSIVE experience and their final design*

Survey results (Table 8) reveal that the majority of the participants felt positive about the experience with the CoHeSIVE app. 75 % of the participants would recommend this app to be used for the co-design

Table 8
Participants' feedback on CoHeSIVE experience and their final design.

Feedback on CoHeSIVE experience and final design		Number of Participants	Frequency (%)
Negative consequences (side effects) from the app	Yes	2	5 %
	No	39	95 %
Recommend this app	Yes	31	75 %
	Yes, but needs improvement	4	10 %
	No or I don't know	6	15 %
Ease of the use of app interface	Very Easy	18	44 %
	Easy	19	46 %
	Neutral	2	5 %
	Uneasy	0	0 %
	Very Uneasy	2	5 %
Ease of designing with the app	Very Easy	23	56 %
	Easy	14	34 %
	Neutral	3	7 %
	Uneasy	1	3 %
	Very Uneasy	0	0 %

phase of the participatory design process. These participants also indicated that the CoHeSIVE app helps not only to visualize and communicate ideas but also to show the human perspective of a design. An additional 10 % would recommend this app in the future only after methodological improvements. These improvement suggestions included the simulation of the effects or impacts of design decisions and the simulation of dynamic features to enhance user experiences. To enrich the design discussion around health, participants suggested that the app could include additional design interventions related to walking paths [9], surrounding amenities [6], amount of people and traffic levels [6], building facades [4], and other urban furniture (e.g., fitness equipment, station piano, art) [6]. Next to that, participants indicated they would like to receive immediate feedback on their design choices in the app. For this, they suggested the app could simulate the effects on night vision [23], shadows [4], wind [2], and sound [1] (numbers in brackets indicate the number of participants mentioning the subject). (See Table 8.)

Table 8
(continue). Participants' feedback on CoHeSIVE experience and their final design.

Feedback on CoHeSIVE experience and final design		Number of Participants	Frequency (%)
Designing with given options for attribute levels	Yes	29	71 %
	No	12	29 %
Feeling Immersed	Very immersed	9	22 %
		23	56 %
	Neutral	4	10 %
		5	12 %
	Not at all immersed	0	0 %
Feeling Presence	Felt present at plaza	3	7 %
		18	44 %
	Neutral	12	29 %
		7	17 %
	Not realistic	1	3 %
	Yes	32	78 %
VR environment is detailed enough	No or After some adjustments	9	22 %
Visual iInformation enables confidence for making design decisions	Very Confident	5	12 %
		20	49 %
	Neutral	7	17 %
		9	22 %
	Not at all confident	0	0 %
	Very confident	2	5 %
		17	41 %
	Neutral	13	32 %
		6	15 %
Participants' confidence about their final design	Not at all confident	3	7 %

Regarding the user interface and features of the CoHeSIVE app, the participants overall hardly experienced negative consequences from using the VR headsets. Only two participants reported experiencing negative consequences such as feelings of claustrophobia, missing eye contact, dizziness because of switching viewpoints, and concentration issues. 90 % of the participants reported that they found the interface of CoHeSIVE easy to use, with 44 % describing it as very easy. Although the interface was considered easy, small issues were reported related to navigation, teleporting, and visual fidelity such as finding succeeding attribute selection panels due to moving locations of panels, confusion about the purpose of floating navigation arrows, and not enough detail in the bird-eye view.

Regarding designing with the app, 90 % of the participants reported that they found it easy to design the station plaza. 71 % of the participants preferred to design the area by selecting among the given options for attribute levels instead of having unrestricted design freedom. Designing with options was mainly appreciated because it is time efficient [10], ending up with more realistic designs [2] and easier for guiding design discussions [1]. For this, it was suggested to add extra attribute levels [6], and let participants decide the type of an attribute (e.g., tree species) [2]. The remaining 29 % of the participants would rather design the attribute profiles freely themselves. These participants reported that this preference is based on their design background and/or their in-depth knowledge of the case area location. Designing freely was preferred by these participants because it is more flexible [1] and less suggestive [1].

Regarding visual fidelity, 78 % of the participants felt immersed while using the app whereas only 51 % of the participants reported feeling presence. The latter can possibly be explained by the visual fidelity which was not realistic enough to feel present. According to 78 % of the participants, the VR environment was detailed enough to understand the spatial arrangement of the plaza. 61 % of the participants indicated that the visual information made them feel (very) confident to make design decisions. The following improvements were suggested for visual fidelity: Add animated people (simulated based on expected behavior) [11], increase texture details (e.g., pavement, grass with shrubs, plinths) [10], more teleporting options or ability to walk through plaza [4], change time conditions (e.g., day/night vision) [4], add compass or fixed top view screen [2], add sounds [2]. Moreover, regarding the clarity of attribute levels, participants were asked whether they could clearly see the difference between the attribute levels. Table 9 shows that the differences between the levels within tree presence, bench presence, and building height were clearly visible. For 10 % to 20 % of the participants, the differences were considered unclear within the attributes tree composition and grass presence.

In the survey, participants were asked to indicate on a 5-level Likert scale to what extent they feel confident about their final design in case it will be implemented in real life. As can be seen in Table 8, overall, 22 % of the participants didn't feel (not at all) confident while 46 % of the participants felt (very) confident that their design could be realized. 32 % of participants felt neutral about the realization of their design.

3.5. Participants' feedback on the use of CoHeSIVE for participatory design

Concerning the use of the CoHeSIVE application for participatory design, the workshop session was concluded with a participatory discussion where one participant was requested to explicitly convey their opinions verbally on his/her design decisions while being immersed. The design process of this participant was screen-casted so that other participants could follow the design process and discuss the decisions. Three participants (each in a different session) presented in this format, and these three participants indicated that it was difficult to

Table 9
The visual clarity of attributes in CoHeSIVE.

Visual Clarity	Tree presence	Tree composition	Bench presence	Grass presence	Building height	Lamppost presence	Fountain presence
Average clarity (1–5)	4,2	3,5	4,3	3,6	4,4	3,8	3,9
Very clear (%)	33	24	33	10	53	17	26
Clear (%)	56	31	63	56	40	50	43
Neutral (%)	5	26	2	22	5	31	24
Unclear (%)	2	14	2	12	2	2	7
Very unclear (%)	2	5	0	0	0	0	0

communicate as they could not see the facial expressions of the audience. On the other hand, 85 % of the audience (the rest of the participants who were watching and discussing) indicated that it was (very) easy to follow the design process and contribute to it through screen-casting. In the overall process, 78 % of the participants indicated they felt it was easy or very easy to communicate or speak while being immersed (see Table 10).

Overall, 93 % of participants indicated that the application can support the communication process between different participants. The following suggestions were made to improve the participatory design process with the app: Include one-on-one sessions between designer and end-user, visualize (health) impacts, such as urban heat island effects, and visualize constraints or thresholds between attributes (e.g., a budget).

4. Discussion

We implemented our *Experiencing the Future Framework* through developing CoHeSIVE and empirically evaluating it through a series of workshops. Extending the proposal by Sheppard (2005), the following five aspects were important (see also Fig. 1). 1) **Make it local.** Rather than evaluating general principles of healthy public space design, we focused on an ongoing local project, the central station plaza in Eindhoven, and engaged with various local stakeholders including citizens. This local approach was introduced at the first workshop resulting in a set of design attributes and tasks associated with the local context. 2) **Make it visual.** We created 3D models of potential design options. 3) **Make it connected.** The design tasks and attributes were framed in the urgency of improving human well-being and the emerging focus on designing healthy public spaces due to the desired densification of inner cities. 4) **Make it experiential.** Using immersive technologies (IVR), we gave participants the opportunity to experience the public space and their design choices first hand using mobile virtual reality headsets. 5) **Make it interactive.** We allowed participants and stakeholders to explore various design options at predefined attribute levels through an interactive user interface (what-if scenarios). Moreover, incorporating the screen-casting feature of the VR devices facilitated a participatory design discussion in the final workshop, enhancing the interactive component further.

During the final workshop with 41 participants, both qualitative (i.e., discussions and open questions in the survey) and quantitative data (i.e.; survey and tracking data) from participants were gathered to evaluate user behavior in CoHeSIVE and the *Experiencing the Future Framework* (user experiences with CoHeSIVE and participation process). Combining qualitative and quantitative evaluations allowed us to compare the subjective and objective experiences of the users. Supporting our framework and developments, the collected quantitative data, although exploratory, was consistent with the qualitative data analysis, enhancing the robustness of our approach and conclusions.

The results show that our proposed framework, which includes embodied, interactive experiences into participatory approaches for designing healthy public spaces, is seen very positively. 75 % of the participants would recommend the CoHeSIVE app to be used for a participatory co-design process. Moreover, most of the participants felt (very) confident that their final design outcome could be realized. From a technology perspective, it should be stressed that, according to the survey results, participants hardly experienced negative consequences with CoHeSIVE. This is important as it indicates the maturation of immersive technologies and significant improvements compared to earlier developments (Fisher & Unwin, 2002). Furthermore, participants reported that the user interface was easy and useful for altering the base scenario into a new design scenario by selecting preferred levels of design attributes (e.g., many trees versus few trees). Selecting levels of design attributes in the CoHeSIVE app was reported to be time-efficient and resulted in realistic design outputs. These results indicate that our design approach (e.g., providing users with pre-selected attributes) leads to enhanced usability of the CoHeSIVE application and that the design process with the CoHeSIVE application is intuitive (without requiring extensive learning times), user-friendly, and time-efficient. Examining the user behavior tracking data, the relatively longer time spent on the first attribute "Tree Presence" and the higher values for overall head movements for this attribute show us that there still is a learning curve for users. In a future study and iteration of the application, randomization of the attributes could help distribute any learning effects more evenly across all attributes. In addition, the brief training phase could also be extended to familiarize users with the interface and design attributes before the actual testing begins. This should mitigate the impact of the learning curve on the recorded interaction times.

While arguments could be made to allow users to freely design urban environments, the overhead and challenges that such approaches create, for example, educating and guiding non-expert users, are in stark contrast to CoHeSIVE, where participants do not require extensive

Table 10
Participants' assessment of communication through CoHeSIVE.

	Communication while being immersed (N = 41)		Communication during screen-casting (*N* = 38)		Application can support the communication process (N = 41)		
	Number of participants	Frequency	Number of participants	Frequency		Number of participants	Frequency
5-very easy	12	29 %	11	27 %	**5-very supportive**	15	37 %
4-easy	20	49 %	24	59 %	**4-supportive**	23	56 %
3-neutral	4	10 %	3	7 %	**3-neutral**	3	7 %
2-uneasy	5	12 %	0	0 %	**2-not supportive**	0	0 %
1-very uneasy	0	0 %	0	0 %	**1-not at all supportive**	0	0 %

training. In addition, giving design freedom to non-expert users might not result in comparable design ideas and solutions, whereas with CoHeSIVE we can grasp emerging tendencies in terms of people's preferences, which can provide quantitative and objective feedback for the decision-makers. As the user behavior tracking results show, the most preferred attribute levels were many and clustered trees, several benches, large grass surfaces, high-rise buildings, more lampposts and the presence of fountain, showing the design outcomes were meaningful. In a future version of this application, it is recommended to include additional attributes and attribute levels, as suggested by participants in the final workshop. This will offer users a greater variety of suggestions, thereby enhancing their design flexibility. Furthermore, looking at the user behavior tracking data, we see that not all attribute levels were explored, especially for the attributes "Tree presence", "Benches" and "Grass". It is possible that people already had preconceptions about these attributes and immediately selected their most preferred levels. For instance, a general conception is that more trees and more grass is always better. Adding more attribute levels could support design flexibility and result in more refined outcomes.

We adopted realistic but medium to low levels of visual fidelity for CoHeSIVE. It is an ongoing discussion of how much visual fidelity is required for immersive experiences across many fields of research (e.g., Gonçalves et al., 2022; Huang & Klippel, 2020). There is no universally acceptable answer. For our project, it was important to create scalable solutions for mobile devices that do not require powerful hardware. While in the long-run, fidelity will improve with newer technologies, it is important to note that plausibility, that is, accepting an immersive environment as useful for real-world decisions, and not fidelity, is often key (Huang, 2021). As documented by the responses of the participants, the levels of fidelity were deemed appropriate but more realism was also on the wish list such as adding animated people/pedestrians and increasing texture details of some features. This is also in line with the findings of van Gisbergen et al. (2019) in which increased realism in VR environments didn't enhance users' experience and natural behavior. Moreover, the visual design of the virtual environment (interface) in CoHeSIVE and the details of the virtual environment were overall perceived positively. However, there were some suggestions for improvement regarding the navigation and teleporting. This was also confirmed by the user behavior tracking data, which showed that only one-third of the participants used teleporting options. The visual design of the virtual environment plays a significant role in users navigating themselves in the virtual environment and there are differences in the navigational learning of young and elderly users (Lokka & Çöltekin, 2019). In future studies, we are planning to address different aspects of fidelity and integrating findings from this growing field of research into CoHeSIVE. Particularly important will be to develop and test custom-made virtual environments and their influences on the outcomes of co-design activities for different user groups.

Regarding the participatory discussion at the end of the final workshop session, the majority of participants indicated they felt it was easy or very easy to communicate or speak while being immersed. Furthermore, the majority of the audience indicated it was easy or very easy to follow the design process and contribute to it through screen-casting. Overall, the follow-up discussion after the study highlighted the potential of embodied, interactive experiences, implemented in CoHeSIVE, to initiate meaningful conversations toward a shared understanding between participating parties resulting in co-designed outcomes. Extending Sheppard's approach to include experiences and interactivity and conceptualizing them into the Experiencing the Future Framework seems to be a prudent choice theoretically and practically for participatory co-design of healthy public spaces, and for future research directions.

Advancing collaborative experiences in VR is one of the cornerstones of future developments, also fueling interest in Metaverse-style developments (Mystakidis, 2022; Pidel & Ackermann, 2020; Šašinka et al., 2019). The ongoing development of CoHeSIVE is aiming for collaborative immersive experiences where all participants share the same virtual space. As such, participants can experience each other's design decisions and discuss them by sharing the same virtual environment. Another advantage of collaborative immersive experiences will be that participants can experience the same virtual environment by being in the same physical space or remotely, without the need for a shared physical space, through online connections (Šašinka et al., 2019). However, as tested in our study, mixed-settings, where some but not all participants are immersed in VR, may have benefits in terms of reduced costs of purchasing many VR equipment but also allow for natural interactions of most participants. However, the discomfort reported by the three headset-wearing participants should be acknowledged. As a discussion point, we advocate that in all future developments, it is important to keep in mind aspects of social discomfort induced by the lack of natural bodily cues in collaborative immersive environments or being "exposed" by being the only headset-wearing participant. Further research on inclusive, respectful, and efficient social aspects of communicating within or with immersive technologies needs to continue (e.g., Skulmowski, 2023).

5. Conclusion and outlook

In this study, we implemented our Experiencing the Future Framework by developing the CoHeSIVE application and conducting a series of three iterative workshops for its development and evaluation. In the final workshop, which included 41 participants, we collected and reported both qualitative and quantitative data to assess user behavior within CoHeSIVE and their experiences within the *Experiencing the Future Framework* (embodied experience through immersion and interactivity for co-design and participation activities). In general, the CoHeSIVE application enabled participants to experience and modify the given virtual built environment in a participatory co-design process for designing a healthy public space. Participants reported that, in general, they had positive experiences with the CoHeSIVE app in terms of its immersion and interactivity components; this finding was also supported by analyzing their behavior data collected from tracking features. The majority of participants would recommend using the CoHeSIVE app for a participatory co-design process. Additionally, most participants felt (very) confident that their final design outcome could be realized. The majority also indicated that the application effectively supported communication between different participants, both during immersive design sessions and while screen-casting. Our evaluation and findings, especially during the participatory session where we used screen-casting, suggest that the affordance of the CoHeSIVE application can initiate meaningful discussions and shared design outcomes among participants. Therefore, this application or an application that follows the *Experiencing the Future Framework* can be valuable in gaining community buy-in for urban design and planning initiatives potentially helping to alleviate the paradox of participation (Wolf et al., 2020). The methodology and the application presented in this paper show that urban design and planning practice can benefit from a thoughtful and strategic application of (emerging) technologies to promote citizen engagement in the co-design processes.

To evaluate our *Experiencing the Future Framework*, we opted for a mixed-methods approach suitable for the goal at hand and allowing for insights corroborated from different methodological perspectives. While exploratory in nature in our case study, the quantitative, behavior-understanding opportunities that immersive technologies offer have long been recognized (Yang et al., 2024; Caserman et al., 2019) and are expanding rapidly now in the wake of Data Science (DS) and Artificial

Intelligence (AI) developments (Nakamatsu et al., 2024). Especially in the field of designing healthy public spaces, immersive experiences offer a plethora of opportunities. The basic tracking information we included into our analysis already provided valuable feedback. We aim to improve our study by adding and analyzing a variety of sensory information. This includes information about eye-tracking, which, for example, provides insights into the cognitive load (Krejtz et al., 2018), as well as movement patterns. Adding external sensors such as skin resistance, opens opportunities to create insights into stress and emotions, thereby understanding the impact of design on subjective and objective well-being (Liu et al., 2023). These developments may provide deeper insights into aspects of healthy public space design that foster or challenge human well-being. Additionally, data collected from immersive experiences such as interaction with the environment or other actors, will create a deeper understanding of the processes of communication and decision-making in participatory design approaches. For instance, in a future study, the user interaction data (i.e., head-tracking data) can be further analyzed in order to understand whether there are differences between user groups so that tailored user interfaces and participatory approaches can be developed. It should be noted, though, that despite all the enthusiasm for the opportunities that the combination of eXtended Reality, Data Science, and Artificial Intelligence offers, we strongly advocate for a critical discussion about ethical considerations (e.g., Zechner, et al., 2023).

To enable better citizen engagement and experiences in co-design workshops in the future, several improvements can be suggested for the last two principles of the *Experiencing the Future Framework* (make it experiential and make it interactive). For instance, in terms of the scalability of the application, CoHeSIVE can be further advanced to be a multi-user VR environment with collaborative capabilities. This way, multiple users can access the virtual environment on-site and off-site. Visual fidelity should also be improved given the potential positive effects on presence (Mizuho et al., 2023). Aligned with this, realism can also be improved by adding more details to elements and by adding more dynamic elements such as moving people and shadows in the virtual environment. Moreover, custom-made visualizations especially regarding navigation and teleportation should be considered according to the needs of different user groups.

For the interactivity principle of our framework, the CoHeSIVE application enabled what-if scenarios by allowing users to instantaneously generate new design scenarios by selecting a level of predefined design attributes. Participants, especially those with non-design backgrounds, appreciated this feature as it made designing easier and more time-efficient, while producing more meaningful outcomes. To improve the effects and outcomes of this feature, the number of attributes and attribute levels should be increased, and the order of the attributes should be randomized. Moreover, as an outlook, to improve the interactivity component and therefore the realistic design outcomes, some restrictions (i.e.; maintenance budget, time budget and/or health outcomes) could be introduced in a serious game setting which would allow participants to think more strategically about their selections.

To enable the implementation of these customizations and modifications, it needs to be investigated how generative AI solutions can be integrated into the design generation phase. This integration could assist the first three principles of the *Experiencing the Future Framework* in tailoring design scenarios to the local context and societal problem, the constraints and regulations of a specific location and catering the application to the needs of different stakeholders. Overall, this study shows that the methodology (the *Experiencing the Future Framework)* suggested and used for developing the CoHeSIVE application is valuable for urban design and planning practices where citizen engagement and participation are required. We are confident that it is also replicable for other contexts such as designing nature-based solutions or community amenities for an urban area. Finally, we encourage the testing of the *Experiencing the Future Framework* in education given the positive effects of immersive learning experiences in architecture, urban design, and planning (Gomez-Tone et al., 2022).

Supplementary data to this article can be found online at https://doi.org/10.1016/j.compenvurbsys.2024.102194.

Funding

This work was supported by the EWUU Alliance, an alliance of TU/e, WUR, UU, and UMC.

CRediT authorship contribution statement

Gamze Dane: Writing – review & editing, Writing – original draft, Supervision, Software, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Suzan Evers:** Writing – review & editing, Writing – original draft, Software, Methodology, Investigation, Formal analysis, Data curation. **Pauline van den Berg:** Writing – review & editing, Supervision, Methodology, Investigation, Funding acquisition. **Alexander Klippel:** Writing – review & editing, Writing – original draft, Software, Methodology. **Timon Verduijn:** Software, Investigation. **Jan Oliver Wallgrün:** Writing – review & editing, Formal analysis. **Theo Arentze:** Writing – review & editing, Methodology, Conceptualization.

Declaration of competing interest

None.

Acknowledgements

We would like to thank all the workshop attendees, the municipality of Eindhoven, and the Urban Development Initiative for their support.

Appendix A. Outputs from first two workshops

Table A1
Initially identified public space attributes that influence user well-being.

Attributes identified both in best practices and in Eindhoven station area	Attributes identified only in best practices
Presence of trees, presence of parasols, presence of benches, amount of driving cars, monotonous or diversity among facades, pavement or grass surface, designated or shared paths, presence of fountain, amount of parked cars, width of paths, size of urban public space, building height, presence of sculptures, presence of active plinth, amount of people, *colours among facades*	*Presence of drinking fountain, different levels of surface, presence of bollards, size of trees, presence of vegetable garden*

Table A2
Selected attributes at the first workshop and their ratings on a five-point scale for their importance and suitability in an immersive virtual reality application.

Attribute	Average importance	Average suitability for IVE
Presence of trees	5.0	4.4
Amount of parked cars	4.4	4.5
Presence of lighting posts	4.1	4.6
Amount of people	4.0	3.9
Designated or shared paths	3.9	3.9
Residential or mixed land-use	3.7	3.3
Presence of benches	3.5	4.5
Building height	3.4	4.0
Width of paths	3.4	4.5

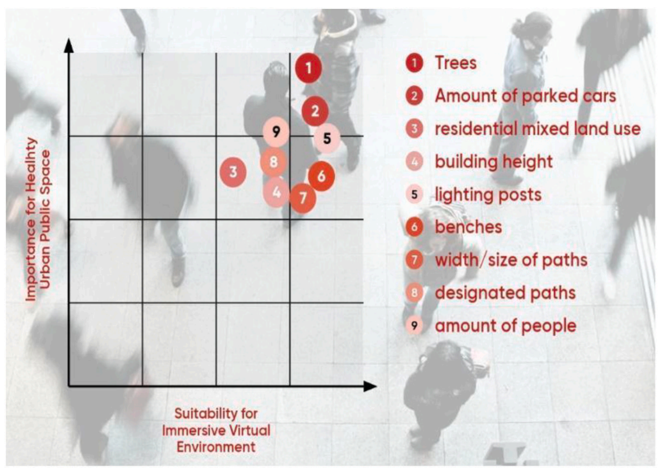


Fig. A1. Selected attributes at the first workshop, and their ratings on a five-point scale for their suitability in an immersive virtual reality application.

Fig. A2. Simulated environment from eye-level perspective with user interface to select (a) attribute panel and (b) attribute level.

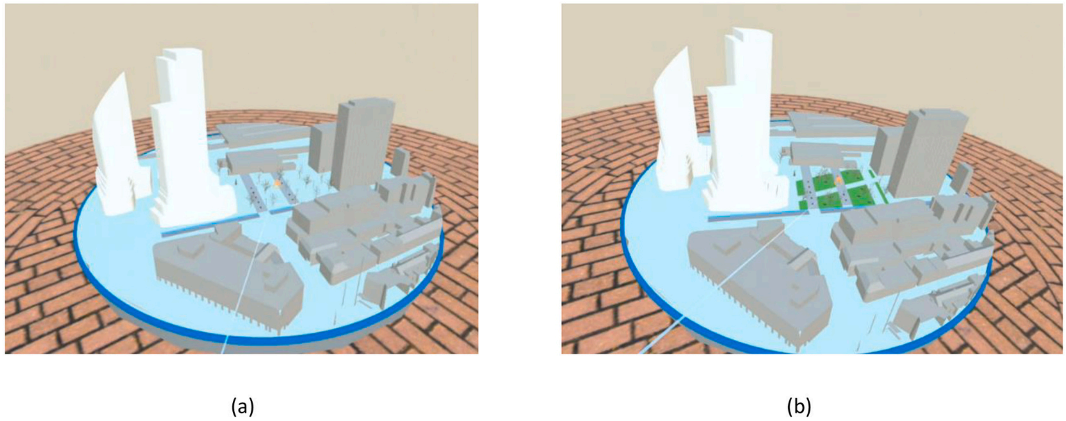


Fig. A3. Simulated environment from the bird-eye perspective: (a) default base scenario and (b) example of designed scenario.

Appendix B. Participant survey

B.1. Personal characteristics

Question #1:	What is your gender? ○ Male ○ Female ○ Other:
Question #2:	In which age group are you? ○ < 25 years ○ 25–34 years ○ 35–44 years ○ 45–54 years ○ 55–64 ○ ≥ 65 years
Question #3:	What is the urbanization level of your living environment? ○ City center ○ City suburbs ○ (small) Town ○ Rural
Question #4:	Do you have an architectural/urban design background? ○ Yes ○ No
Question #5:	How satisfied are you with your current life? *Not satisfied* O O O O O *Very satisfied*
Question #6:	How important do you think the influence of using (urban) plazas is on your health? *Not important* O O O O O *Very important*
Question #7:	How often do you visit (e.g., passing by) the current urban public space used in this case study; the station plaza of Eindhoven? ○ Daily ○ Weekly ○ 1–2 per month ○ Less than once per month ○ Less than once per year
Question #8:	To what extent are you familiar with the use of IVR? *Very unfamiliar* O O O O O *Very familiar Very unfamiliar* O O O O O *Very familiar*
Question #9:	Have you attended the previous workshop(s)? Yes No *Workshop 1 Identifying attributes* O O *Workshop 2 Identifying IVR features* O O
Question #10:	Did you experience side effects such as cyber sickness, fatigue, nausea or concentration issues? *No fatigue* O O O O O *Extreme fatigue* *Complete concentrated* O O O O O *No concentration* Have you experienced other side effects? *No cyber sickness* O O O O O *Extreme cyber sickness*

B.2. Self-made Final Design

How much did the following attributes help you to adjust the base design in a way that made you feel more comfortable to wait in the station plaza for 15 min in the given circumstances?

	Not at all important	Not important	Neutral	Important	Very important
Amount of trees:					
Composition of trees:					
Amount of benches:					
Amount of grass coverage:					
Height of surrounding buildings:					
Amount of lampposts:					
Presence of fountain:					

Do you think your design decisions might have an impact on your well-being?

	Explain the possible impact of one or more physical interventions you made
To feel safe while waiting:	
To feel relaxed while waiting:	
To be social while waiting:	
To be active while waiting:	
To use the plaza for other activities:	

B.3. IVR application: Features and Interface

Question #1:	What feeling is dominant in experiencing the application (e.g., fun, exciting, annoying, challenging)?
Question #2:	Was the interface (the selecting panel with the controllers) of the application easy to understand and use?
	Very uneasy O O O O O *Very easy*
Question #3:	Were there specific (technical) issues regarding the interface you found difficult? If specific, for which issues you needed help from the researchers?
Question #4:	To what extent was it clear to you what the researchers are investigating?
	Very unclear O O O O O *Very clear*
Question #5:	Did you feel it was easy to design the environment (e.g., make changes in the environment)?
	Very uneasy O O O O O *Very easy*
Question #6:	Do you feel you can express your opinion better by designing the environment yourself, or would you rather choose between given options of design attributes as in the provided IVR application?
Question #7:	Would you recommend others such an application for a (co-) design process?

B.4. IVR application: Visual fidelity

Question #1:	Did you find the VR environment detailed enough to understand the (spatial) arrangement of the plaza?
Question #2:	Did the visual information make you confident to take your design decision (e.g., quality of image, position of the camera)?
	Not at all confident O O O O O *Very confident*
Question #3:	What should be changed/improved/added to the understanding?
Question #4:	Could you clearly perceive the differences between the attribute levels?

Attribute	*Very unclear*	*Unclear*	*Neutral*	*Clear*	*Very clear*
Amount of trees	O	O	O	O	O
Composition of trees	O	O	O	O	O
Amount of benches	O	O	O	O	O
Amount of grass coverage	O	O	O	O	O
Height of buildings	O	O	O	O	O
Amount of lampposts	O	O	O	O	O
Presence of fountain	O	O	O	O	O

Question #5:	Did you feel immersed and present in the environment?
	Not immersed O O O O O *Very immersed*
	Not realistic O O O O O *Felt present a plaza*
Question #6:	To what extent do you feel confident about your final design in case it will be implemented in real life?
	Not at all confident O O O O O *Very confident*

B.5. IVR application: The (co-)design process

Question #1:	To what extent was it easy to communicate with someone else while being immersed?
	Very uneasy O O O O O *Very easy*
Question #2:	In the discussion afterwards, do you think it was easy to follow the design process of another participant by following it through screen-casting?
	Very uneasy O O O O O *Very easy*

If uneasy, what would you like to improve?

Question #3:	To what extent do you think the application can support the communication between different stakeholders (e.g., designers and citizens)? In addition, how could it be improved to support communication?
	Not supportive O O O O O *Very supportive* What would you like to improve?

References

© 3DBAG by tudelft3d and 3DGI. (2024). Retrieved July 10, 2024, from https://3dbag.nl/en/viewer.

Alwah, A. A., Li, W., Alwah, M. A., & Shahrah, S. (2021). Developing a quantitative tool to measure the extent to which public spaces meet user needs. *Urban Forestry & Urban Greening, 62*, Article 127152.

Amado, M. P., Santos, C. V., Moura, E. B., & Silva, V. G. (2010). Public participation in sustainable urban planning. *International journal of human and social sciences, 5*(2), 102–108.

Arnstein, S. R. (1969). A ladder of citizen participation. *Journal of the American Institute of Planners, 35*(4), 216–224.

Baldauf, M., Zimmermann, H. D., Baer-Baldauf, P., & Bekiri, V. (2023). Virtual reality for smart government – Requirements, opportunities, and challenges. In F. Nah, & K. Siau (Eds.), *Lecture notes in computer science: Vol. 14038. HCI in business, government and organizations. HCII 2023*. Cham: Springer. https://doi.org/10.1007/978-3-031-35969-9_1.

Barbot, B., & Kaufman, J. C. (2020). What makes immersive virtual reality the ultimate empathy machine? Discerning the underlying mechanisms of change. *Computers in Human Behavior, 111*, Article 106431. https://doi.org/10.1016/j.chb.2020.106431

Batty, M. (2024). Digital twins in city planning. *Nature Computational Science, 4*(3), 192–199. https://doi.org/10.1038/s43588-024-00606-7

Borgers, A., Brouwer, M., Kunen, T., Jessurun, J., & Janssen, I. (2010). A virtual reality tool to measure shoppers' tenant mix preferences. *Computers, Environment and Urban Systems, 34*(5), 377–388.

Bouzguenda, I., Fava, N., & Alalouch, C. (2022). Would 3D digital participatory planning improve social sustainability in smart cities? An empirical evaluation study in less-advantaged areas. *Journal of Urban Technology, 29*(3), 41–71. https://doi.org/10.1080/10630732.2021.1900772

Caserman, P., Garcia-Agundez, A., Konrad, R., Göbel, S., & Steinmetz, R. (2019). Real-time body tracking in virtual reality using a vive tracker. *Virtual Reality, 23*, 155–168.

Casini, M. (2022). Extended reality for smart building operation and maintenance: A review. *Energies, 15*(10), 3785. https://doi.org/10.3390/en15103785

Chassin, T., Ingensand, J., Christophe, S., & Touya, G. (2022). Experiencing virtual geographic environment in urban 3D participatory e-planning: A user perspective. *Landscape and Urban Planning, 224*, Article 104432. https://doi.org/10.1016/j.landurbplan.2022.104432

Chowdhury, S., & Schnabel, M. A. (2019). Laypeople's collaborative immersive virtual reality design discourse in neighborhood design. *Frontiers in Robotics and AI, 6*, 97. https://doi.org/10.3389/frobt.2019.00097

Cleaver, F. (1999). Paradoxes of participation: Questioning participatory approaches to development. *Journal of International Development, 11*(4), 597–612.

Cramer, V., Torgersen, S., & Kringlen, E. (2004). Quality of life in a City: The effect of population density. *Social Indicators Research, 69*, 103–116. https://doi.org/10.1023/B:SOCI.0000032663.59079.0b

Daher, E., Maktabifard, M., Kubicki, S., Decorme, R., Pak, B., & Desmaris, R. (2021). Tools for citizen engagement in urban planning. *Holistic Approach for Decision Making Towards Designing Smart Cities*, 115–145.

Davies, R. C. (2004). Adapting virtual reality for the participatory Design of Work Environments. *Computer Supported Cooperative Work (CSCW), 13*, 1–33.

Ehab, A., & Heath, T. (2023). Exploring immersive co-design: Comparing human interaction in real and virtual elevated urban spaces in London. *Sustainability, 15*(12), 9184. https://doi.org/10.3390/su15129184

Evans-Cowley, J., & Hollander, J. (2010). The new generation of public participation: Internet-based participation tools. *Planning Practice and Research, 25*(3), 397–408.

Evers, S., Dane, G. Z., Van Den Berg, P. E. W., Klippel, A. K. A. J., Verduijn, T., & Arentze, T. A. (2023). Designing healthy public spaces: A participatory approach through immersive virtual reality. *AGILE: GIScience Series, 4*, 1–8. https://doi.org/10.5194/agile-giss-4-24-2023

Fisher, P. F., & Unwin, D. (Eds.). (2002). *Virtual reality in geography*. London, New York: Taylor & Francis.

van Gisbergen, M., Kovacs, M., Campos, F., van der Heeft, M., & Vugts, V. (2019). What we Don't know. The effect of realism in virtual reality on experience and behaviour. In tom Dieck, M., Jung, T. (Ed.), *Augmented reality and virtual reality. Progress in IS*. Cham: Springer. https://doi.org/10.1007/978-3-030-06246-0_4.

Gomez-Tone, H. C., Alpaca Chávez, M., Vásquez Samalvides, L., & Martin-Gutierrez, J. (2022). Introducing immersive virtual reality in the initial phases of the design process—Case study: Freshmen designing ephemeral architecture. *Buildings, 12*, 518. https://doi.org/10.3390/buildings12050518

Gonçalves, G., Coelho, H., Monteiro, P., Melo, M., & Bessa, M. (2022). Systematic review of comparative studies of the impact of realism in immersive virtual experiences. *ACM Computing Surveys, 55*(6). https://doi.org/10.1145/3533377

Healey, P. (1998). Building institutional capacity through collaborative approaches to urban planning. *Environment and Planning A: Economy and Space, 30*(9), 1531–1546. https://doi.org/10.1068/a301531

Honey-Rosés, J., & Zapata, O. (2021). The impact of residential densification on perceptions of public space: A field experiment. *Journal of the American Planning Association, 87*(2), 282–295. https://doi.org/10.1080/01944363.2020.1846597

Huang, J. (2021). *The effects of visual realism on cognitive constructs, spatial memory and learning in virtual reality*. State College, PA, USA: The Pennsylvania State University (PhD thesis).).

Huang, J., & Klippel, A. (2020). The effects of visual realism on spatial memory and exploration patterns in virtual reality. In R. J. Teather (Ed.), *ACM digital library. VRST '20: 26th ACM symposium on virtual reality software and technology* (pp. 1–11). New York, NY, United States: Association for Computing Machinery. https://doi.org/10.1145/3385956.3418945.

Huang, J., Lucash, M. S., Scheller, R. M., & Klippel, A. (2021). Walking through the forests of the future: Using data-driven virtual reality to visualize forests under climate change. *International Journal of Geographical Information Science, 35*(6), 1155–1178. https://doi.org/10.1080/13658816.2020.1830997

Jamei, E., Mortimer, M., Seyedmahmoudian, M., Horan, B., & Stojcevski, A. (2017). Investigating the role of virtual reality in planning for sustainable smart cities. *Sustainability, 9*(11), 2006. https://doi.org/10.3390/su9112006

Jerald, J., LaViola, J. J., & Marks, R. (2017). *VR interactions. In ACM SIGGRAPH 2017 courses (SIGGRAPH '17)* (pp. 1–105). New York, NY, USA: Association for Computing Machinery. https://doi.org/10.1145/3084873.3084900. Article 19.

Jiang, H., Pan, H., Lin, Y., & Geertman, S. (2023). Hacking corporate smart cities under COVID-19: Towards a smart governance approach. *Journal of Urban Technology, 30*(4), 71–81. https://doi.org/10.1080/10630732.2023.2255122

Jones, D., Snider, C., Nassehi, A., Yon, J., & Hicks, B. (2020). Characterising the digital twin: A systematic literature review. *CIRP Journal of Manufacturing Science and Technology, 29*, 36–52. https://doi.org/10.1016/j.cirpj.2020.02.002

Khateeb, S. E., & Shawket, I. M. (2022). A new perception; generating well-being urban public spaces after the era of pandemics. *Developments in the Built Environment, 9*, Article 100065.

Kim, S., Kim, J., & Kim, B. (2020). Immersive virtual RealityAided conjoint analysis of Urban Square preference by living environment. *Sustainability, 12*(16), 6440. https://doi.org/10.3390/su12166440

Klippel, A., Zhao, J., Oprean, D., Wallgrün, J. O., Stubbs, C., La Femina, P., & Jackson, K. L. (2020). The value of being there: Toward a science of immersive virtual field trips. *Virtual Reality, 24*(4), 753–770. https://doi.org/10.1007/s10055-019-00418-5

Krejtz, K., Duchowski, A. T., Niedzielska, A., Biele, C., & Krejtz, I. (2018). Eye tracking cognitive load using pupil diameter and microsaccades with fixed gaze. *PLoS One, 13*(9), Article e0203629. https://doi.org/10.1371/journal.pone.0203629

Kunze, A., Halatsch, J., Vanegas, C., Jacobi, M. M., Turkienicz, B., & Schmitt, G. (2011). A conceptual participatory design framework for urban planning. In *Proceedings of*

eCAADe 2011, respecting fragile places: Ljubljana. https://doi.org/10.52842/conf.ecaade.2011.895, 895–90.
Lee, B., Brown, D., Lee, B., Hurter, C., Drucker, S., & Dwyer, T. (2021). Data Visceralization: Enabling deeper understanding of data using virtual reality. *IEEE Transactions on Visualization and Computer Graphics, 27*(2), 1095–1105. https://doi.org/10.1109/TVCG.2020.3030435
Legge, K. (2020). Public seating–small important places. In *The Routledge handbook of Placemaking* (pp. 439–448). Routledge.
Liao, B., van der Berg, P. E. W., van Wesemael, P. J. V., & Arentze, T. A. (2022). Individuals' perception of walkability: Results of a conjoint experiment using videos of virtual environments. *Cities, 125*, Article 103650. https://doi.org/10.1016/j.cities.2022.103650
Liu, T., Liu, L., Gou, G.-Y., Fang, Z., Sun, J., Chen, J., Cheng, J., Han, M., Ma, T., Liu, C., & Xue, N. (2023). Recent advancements in physiological, biochemical, and multimodal sensors based on flexible substrates: Strategies, technologies, and integrations. *ACS Applied Materials & Interfaces, 15*(18), 21721–21745. https://doi.org/10.1021/acsami.3c02690
Liu, Y., van Marrewijk, A., Houwing, E. J., & Hertogh, M. (2019). The co-creation of values- in-use at the front end of infrastructure development programs. *International Journal of Project Management, 37*(5), 684–695. https://doi.org/10.1016/J.IJPROMAN.2019.01.013
Lokka, I. E., & Çöltekin, A. (2019). Perspective switch and spatial knowledge acquisition: Effects of age, mental rotation ability and visuospatial memory capacity on route learning in virtual environments with different levels of realism. *Cartography and Geographic Information Science, 47*(1), 14–27. https://doi.org/10.1080/15230406.2019.1595151
Lu, Y., Sun, G., Sarkar, C., Gou, Z., & Xiao, Y. (2018). Commuting mode choice in a high-density city: Do land-use density and diversity matter in Hong Kong? *International Journal of Environmental Research and Public Health, 15*(5), 920.
Lyu, K., Brambilla, A., Globa, A., & De Dear, R. (2023). An immersive multisensory virtual reality approach to the study of human-built environment interactions. *Automation in Construction, 150*, Article 104836. https://doi.org/10.1016/j.autcon.2023.104836
Mannarini, T., Fedi, A., & Trippetti, S. (2010). Public involvement: How to encourage citizen participation. *Journal of Community & Applied Social Psychology, 20*(4), 262–274.
Matthys, M., De Cock, L., Mertens, L., Boussauw, K., De Maeyer, P., & Van De Weghe, N. (2023). Rethinking the public space design process using extended reality as a game changer for 3D co-design. *Applied Sciences, 13*(14), 8392. https://doi.org/10.3390/app13148392
Mehta, V. (2013). Evaluating public space. *Journal of Urban Design, 19*(1), 53–88. https://doi.org/10.1080/13574809.2013.854698
Mizuho, T., Narumi, T., & Kuzuoka, H. (2023). Effects of the Visual Fidelity of Virtual Environments on Presence, Context-dependent Forgetting, and Source-monitoring Error. *IEEE Transactions on Visualization and Computer Graphics, 29*(5), 2607–2614. https://doi.org/10.1109/TVCG.2023.3247063
Mouratidis, K. (2019). Compact city, urban sprawl, and subjective well-being. *Cities, 92*, 261–272.
Mueller, J., Lu, H., Chirkin, A., Klein, B., & Schmitt, G. (2018). Citizen design science: A strategy for crowd-creative urban design. *Cities, 72*, 181–188.
Municipality of Eindhoven. (2021). Ontwikkelvisie & ontwikkelkader Fellenoord: Internationale Knoop XL. https://raadsinformatie.eindhoven.nl/document/11789874/1#search=%22ontwikkelvisie%20fellenoord%22.
Mystakidis, S. (2022). *Metaverse. Encyclopedia, 2*(1), 486–497. https://doi.org/10.3390/encyclopedia2010031
Nakamatsu, K., Patnaik, S., Kountchev, R., & (Eds.).. (2024). *AI technologies and virtual reality* (Vol. 382). Singapore: Springer Nature Singapore. https://doi.org/10.1007/978-981-99-9018-4
Namatama, N. (2020). An assessment of stakeholders' participation in land use planning process of Luapula Province planning authority. *Land Use Policy, 97*, Article 104735.
Oomen, M., Haase, R., Wiersma, N., van Wesemael, P., Azadi, S., Ghodsvali, M., Kasraian, D., & Dane, G. (2024). *Manifest of urban planning reimagined: A digitally enabled new way of working. Zenodo*. https://doi.org/10.5281/zenodo.10575357
Paes, D., Arantes, E., & Irizarry, J. (2017). Immersive environment for improving the understanding of architectural 3D models: Comparing user spatial perception between immersive and traditional virtual reality systems. *Automation in Construction, 84*, 292–303.
Pellas, N., Mystakidis, S., & Kazanidis, I. (2021). Immersive virtual reality in K-12 and higher education: A systematic review of the last decade scientific literature. *Virtual Reality, 25*(3), 835–861. https://doi.org/10.1007/s10055-020-00489-9
Pettit, C., Bakelmun, A., Lieske, S. N., Glackin, S., Thomson, G., Shearer, H., Dia, H., & Newman, P. (2018). Planning support systems for smart cities. *City, Culture and Society, 12*, 13–24.
Pettit, C. J., Glackin, S., Trubka, R., Ngo, T., Lade, O., Newton, P., & Newman, P. (2014). A co-design prototyping approach for building a precinct planning tool. *ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences, II-2*, 47–53. https://doi.org/10.5194/isprsannals-II-2-47-2014
Pfeffer, K., Baud, I., Denis, E., Scott, D., & Sydenstricker-Neto, J. (2013). Participatory spatial knowledge management tools. *Information, Communication and Society, 16*(2), 258–285. https://doi.org/10.1080/1369118X.2012.687393
Pidel, C., & Ackermann, P. (2020). Collaboration in virtual and augmented reality: A systematic overview. In L. T. de Paolis, & P. Bourdot (Eds.), *Augmented reality, virtual reality, and computer graphics* (pp. 141–156). Cham: Springer International Publishing.
Portman, M. E., Natapov, A., & Fisher-Gewirtzman, D. (2015). To go where no man has gone before: Virtual reality in architecture, landscape architecture and environmental planning. *Computers, Environment and Urban Systems, 54*, 376–384.
Potkonjak, V., Gardner, M., Callaghan, V., Mattila, P., Guetl, C., Petrović, V. M., & Jovanović, K. (2016). Virtual laboratories for education in science, technology, and engineering: A review. *Computers & Education, 95*, 309–327. https://doi.org/10.1016/j.compedu.2016.02.002
Rzeszewski, M., & Orylski, M. (2021). Usability of WebXR visualizations in urban planning. *ISPRS International Journal of Geo-Information, 10*(11), 721.
Sanders, E. B. N., & Stappers, P. J. (2008). Co-creation and the new landscapes of design. *Co-design, 4*(1), 5–18.
Šašinka, Č., Stachoň, Z., Sedlák, M., Chmelík, J., Herman, L., Kubíček, P., Šašinková, A., Doležal, M., Tejkl, H., Urbánek, T., et al. (2019). Collaborative immersive virtual environments for education in geography. *ISPRS International Journal of Geo-Information, 8*, 3. https://doi.org/10.3390/ijgi8010003
Schnabel, M., & Chowdhury, S. (2020). *VR unmatched - leveraging non-experts as co-urban designers* (CAADRIA proceedings).
Schrom-Feiertag, H., Stubenschrott, M., Regal, G., Matyus, T., & Seer, S. (2020, May). An interactive and responsive virtual reality environment for participatory urban planning. In *Proceedings of the 11th Annual Symposium On Simulation For Architecture and Urban Design* (pp. 1–7).
Scoble, R., & Israel, S. (2017). *The fourth transformation: How augmented reality and artificial intelligence change everything* (1st ed.). Charleston, S.C: Patrick Brewster Press; CreateSpace, a DBA of On-Demand Publishing, LLC [United States],.
Sheppard, S. R. (2015). Making climate change visible: A critical role for landscape professionals. *Landscape and Urban Planning, 142*, 95–105.
Sheppard, S. R. J. (2005). Landscape visualisation and climate change: The potential for influencing perceptions and behaviour. *Environmental Science & Policy, 8*(6), 637–654. https://doi.org/10.1016/j.envsci.2005.08.002
Sheppard, S. R. J. (2012). *Visualizing climate change: A guide to visual communication of climate change and developing local solutions*. Abingdon, Oxon: Routledge.
Sherman, W. R., & Craig, A. B. (2003). *Understanding virtual reality*. Amsterdam, The Netherlands: Elsevier. ISBN 978–1–55860-353-0.
Shin, B., Floch, J., Rask, M., Bæck, P., Edgar, C., Berditchevskaia, A., Mesure, P., & Branlat, M. (2024). A systematic analysis of digital tools for citizen participation. *Government Information Quarterly, 41*(3), Article 101954.
Simpson, M., Zhao, J., & Klippel, A. (2017, October). Take a walk: Evaluating movement types for data visualization in immersive virtual reality. In *Proceedings of Workshop on Immersive Analytics (IA)* (pp. 1–6).
Skulmowski, A. (2023). Ethical issues of educational virtual reality. *Computers & Education: X Reality, 2*, Article 100023.
Smith, R. C., & Iversen, O. S. (2018). Participatory design for sustainable social change. *Design Studies, 59*, 9–36. https://doi.org/10.1016/j.destud.2018.05.005
Steen, M. (2013). Co-design as a process of joint inquiry and imagination. *Design Issues, 29*(2), 16–28. https://doi.org/10.1162/DESI_a_00207
Steuer, J., Biocca, F., & Levy, M. R. (1995). Defining virtual reality: Dimensions determining telepresence. *Communication in the age of virtual reality, 33*(37–39), 1.
Sugiyama, T., Carver, A., Koohsari, M. J., & Veitch, J. (2018). Advantages of public green spaces in enhancing population health. *Landscape and Urban Planning, 178*, 12–17.
Thorpe, A. (2017). Rethinking participation, rethinking planning. *Planning Theory & Practice, 18*(4), 566–582.
Toukola, S., & Ahola, T. (2022). Digital tools for stakeholder participation in urban development projects. *Project Leadership and Society, 3*, Article 100053. https://doi.org/10.1016/j.plas.2022.100053
Turken, A. O., & Eyuboglu, E. E. (2021). E-participatory approaches in urban design. *Journal of Contemporary Urban Affairs, 5*(2), 169–182.
Urton, D., & Murray, D. (2021). Project manager's perspectives on enhancing collaboration in multidisciplinary environmental management projects. *Project Leadership and Society, 2*, Article 100008. https://doi.org/10.1016/j.plas.2021.100008
Van Cauwenbergh, N., Ciuró, A. B., & Ahlers, R. (2018). Participatory processes and support tools for planning in complex dynamic environments: A case study on web-GIS based participatory water resources planning in Almeria, Spain. *Ecology and Society, 23*(2). https://www.jstor.org/stable/26799081.
Van den Berg, P., Weijs-Perrée, M., Dane, G., van Vliet, E., Liu, H., Sun, S., & Borgers, A. (2022). A comparative study of Urban Park preferences in China and the Netherlands. *International Journal of Environmental Research and Public Health, 19*, 4632. https://doi.org/10.3390/ijerph19084632
Van Leeuwen, J. P., Hermans, K., Jylhä, A., Quanjer, A. J., & Nijman, H. (2018). *Effectiveness of virtual reality in participatory urban planning: A case study* (pp. 128–136). Proceedings of the 4th media architecture biennale conference. https://doi.org/10.1145/3284389.3284491
Van Vliet, E., Dane, G., Weijs-Perrée, M., van Leeuwen, E., van Dinter, M., van den Berg, P., Borgers, A., & Chamilothori, K. (2021). The influence of Urban Park attributes on user preferences: Evaluation of virtual parks in an online stated-choice experiment. *International Journal of Environmental Research and Public Health, 18*(1), 212. https://doi.org/10.3390/ijerph18010212
van Veghel, J., Dane, G., Agugiaro, G., et al. (2024). Human-centric computational urban design: Optimizing high-density urban areas to enhance human subjective well-being. *Computational Urban Science, 4*, 13. https://doi.org/10.1007/s43762-024-00124-2
Webb, R., Bai, X., Smith, M. S., Costanza, R., Griggs, D., Moglia, M., … Thomson, G. (2018). Sustainable urban systems: Co-design and framing for transformation. *Ambio, 47*(1), 57–77. https://doi.org/10.1007/s13280-017-0934-6

Williams, T., Vo, H., Samset, K., & Edkins, A. (2019). The front-end of projects: A systematic literature review and structuring. *Production Planning and Control, 30*(14), 1137–1169. https://doi.org/10.1080/09537287.2019.1594429

Wilson, A., Tewdwr-Jones, M., & Comber, R. (2019). Urban planning, public participation and digital technology: App development as a method of generating citizen involvement in local planning processes. *Environment and Planning B: Urban Analytics and City Science, 46*, 286–302.

Wirdelöv, J. (2020). The trash bin on stage: On the sociomaterial roles of street furniture. *Urban Planning, 5*(4), 121–131.

Wolf, M., Söbke, H., & Wehking, F. (2020). Mixed reality media-enabled public participation in urban planning: A literature review. In *Augmented reality and virtual reality: Changing realities in a dynamic world* (pp. 125–138). Cham, Switzerland: Springer.

Wood, L., Hooper, P., Foster, S., & Bull, F. (2017). Public green spaces and positive mental health–investigating the relationship between access, quantity and types of parks and mental wellbeing. *Health & Place, 48*, 63–71.

Yang, S., Dane, G., van den Berg, P., & Arentze, T. (2024). Influences of cognitive appraisal and individual characteristics on citizens' perception and emotion in urban environment: Model development and virtual reality experiment. *Journal of Environmental Psychology, 102309*. https://doi.org/10.1016/j.jenvp.2024.102309

Zarraonandia, T., Díaz, P., Montero, A., & Aedo, I. (2016). Exploring the benefits of immersive end user development for virtual reality. In C. García, P. Caballero-Gil, M. Burmester, & A. Quesada-Arencibia (Eds.), *Ubiquitous Computing and Ambient Intelligence*. Cham: Springer. https://doi.org/10.1007/978-3-319-48746-5_46. UCAmI 2016. Lecture notes in computer science, vol Vol. 10069.

Zechner, O., Pretolesi, D., Jaespert, E., Guirao, D. G., & Tscheligi, M. (2023). Ethical considerations for AI-driven adaptive virtual environments in XR training for first responders: An industry perspective. In *In 2023 IEEE international conference on metrology for eXtended reality*. Artificial Intelligence and Neural Engineering (MetroXRAINE).

Zhao, J., & Klippel, A. (2019). Scale—Unexplored opportunities for immersive Technologies in Place-based Learning. In *2019 IEEE conference on virtual reality and 3D user interfaces (VR)* (pp. 155–162). https://doi.org/10.1109/VR.2019.8797867